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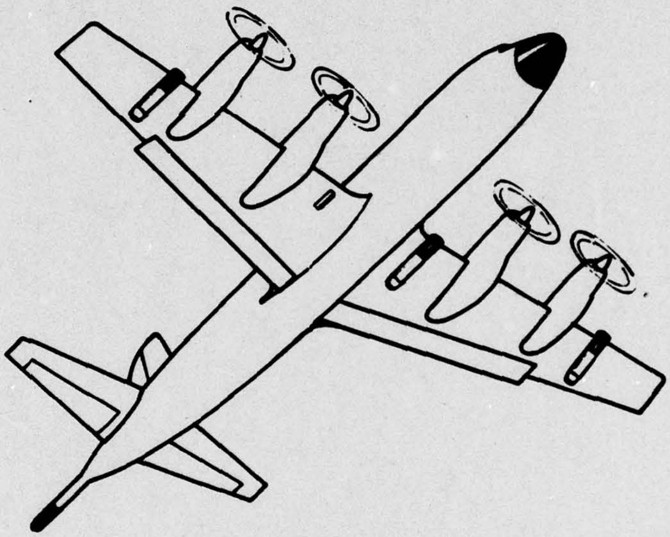
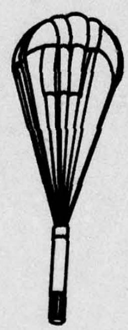
AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM)

PROGRESS REPORT FOR 1977





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This report documents the technology accomplishments in the Air Deployed Oceanographic Mooring (ADOM) program during 1977. Open ocean and ice covered ocean mooring systems were investigated. Both systems are configured to measure temperature, conductivity, and pressure. The actions, analyses, and investigations necessary in the continuation of the ADOM Feasibility Study are presented.

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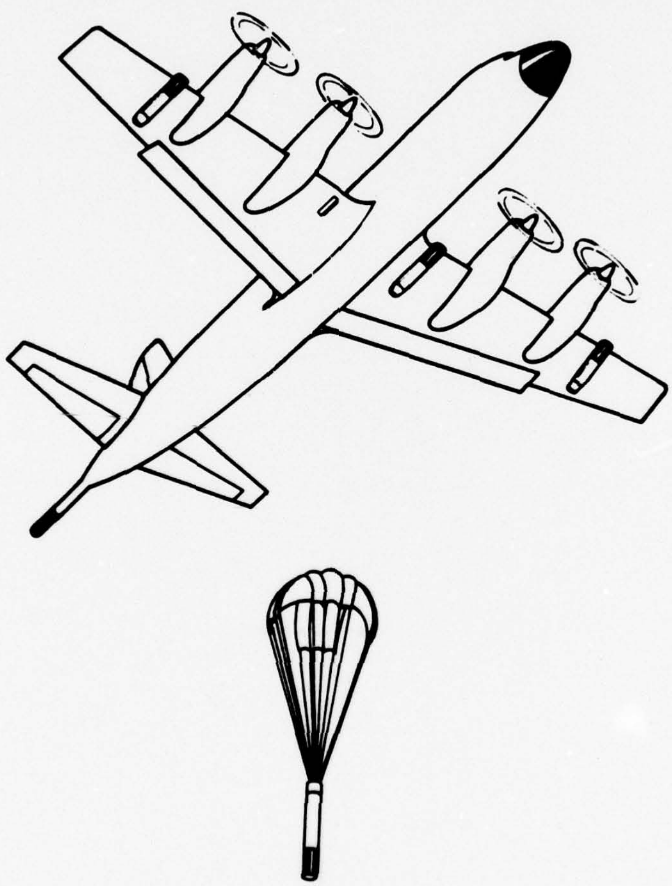

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EXECUTIVE SUMMARY

The purpose of this document is to present the accomplishments in the Air Deployed Oceanographic Mooring (ADOM) program during 1977. A wide variety of scientific investigations can be pursued with air deployed oceanographic moorings which are configured to specific scientific requirements. Also, a number of important oceanographic studies could be accomplished by deploying oceanographic moorings through the polar sea ice from long range aircraft.

Two mooring systems were investigated:

a. open ocean moored system, and
b. ice covered ocean suspended system.

Both systems are configured to measure temperature, conductivity, and pressure; however, the system design will maintain the flexibility to add additional sensors, when proven.

The open ocean moored system, Figure 1, essentially is a subsurface instrumented mooring. The electronics and power supply are located in the subsurface buoy. The sensor array forms the upper portion of the mooring line. Data retrieval is by acoustic link to an independent drifting sonobuoy or through a tether to a surface float.

The ice covered ocean suspended system, when deployed, would consist of an ice penetration system, a buoyant structure which would become frozen into the ice and a suspended sensor array maintained as near vertical as is practical by a sinker as shown in Figure 2. The electronic system would be essentially identical to the open ocean moored ADOM.

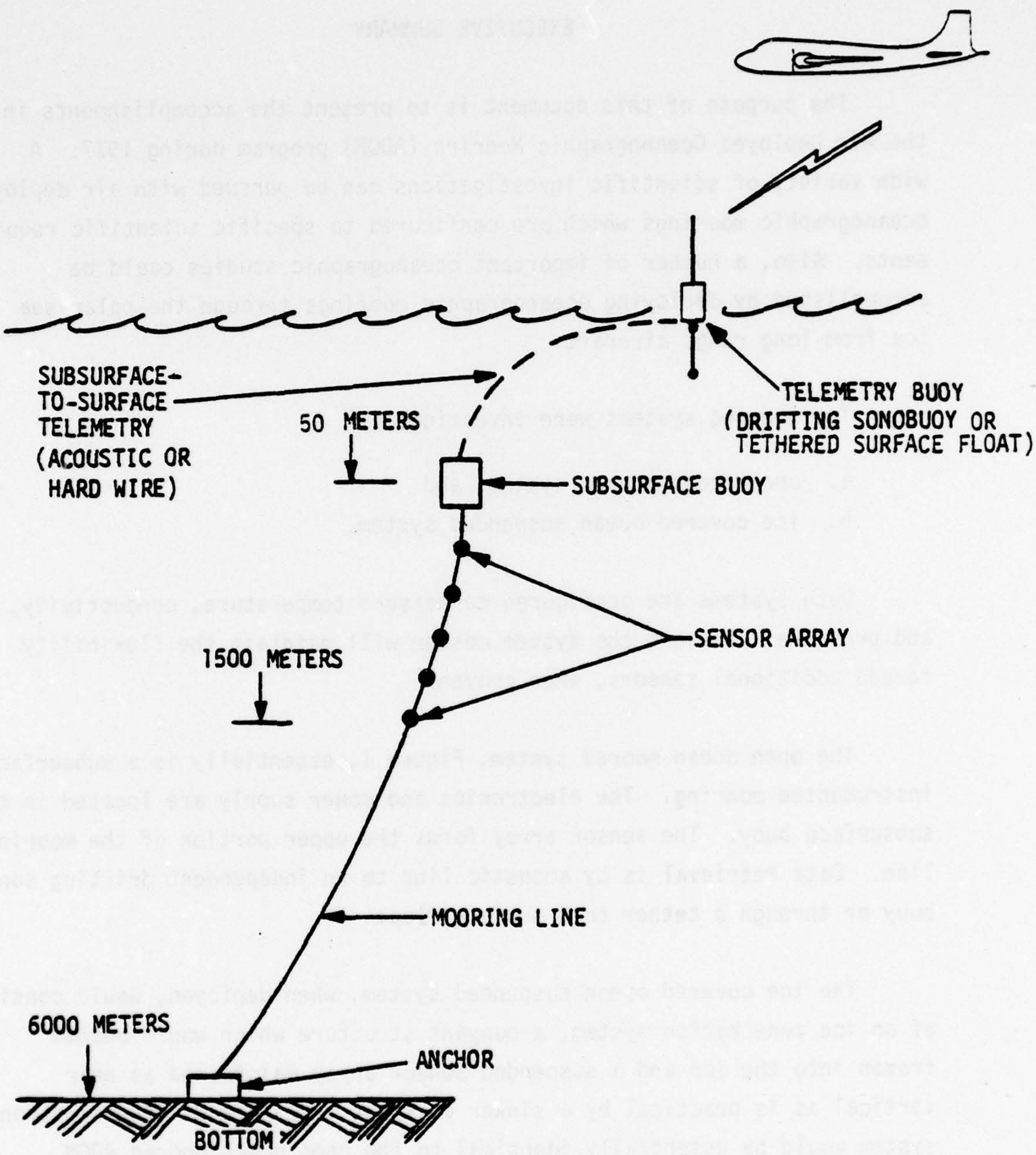

Figure 1. Open Ocean Moored System

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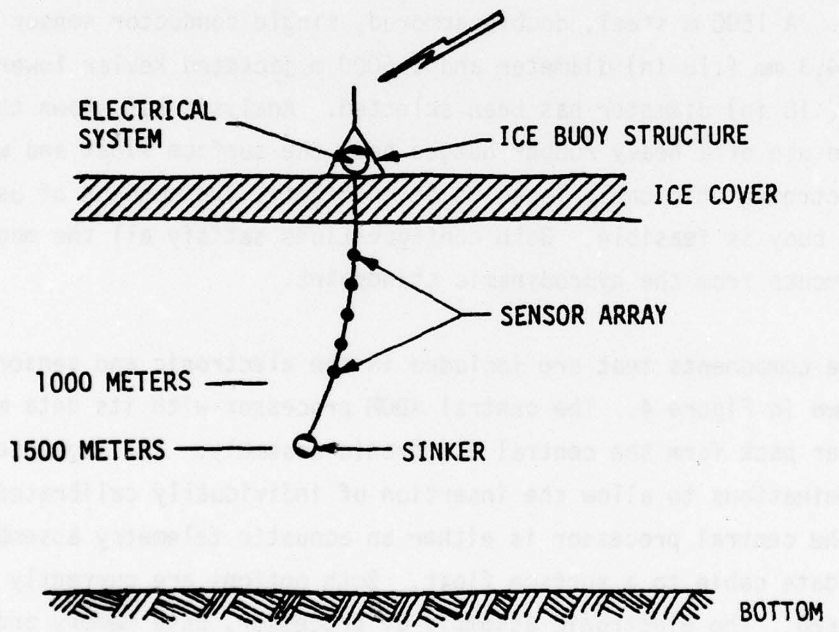

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Figure 2 . Ice Covered Ocean Suspended System

The open ocean moored subsystem is composed of the buoys, mooring assembly and decelerator assembly. Figure 3 presents the two most promising configurations for an ADOM, with and without a surface buoy. The buoy system has been conceptually packaged and consideration made to the store capability with the P3 aircraft, the deployment from the aircraft with a multi-stage decelerator, and the self mooring sequence. A boat-tail has been employed to reduce store aerodynamic drag and to allow attachment of the store to the aircraft underwing location within the allowable physical envelope and with the center of gravity correctly located. A 1500 m steel, double armored, single conductor sensor cable with a 4.3 mm (.18 in) diameter and a 6000 m jacketed Kevlar lower cable of 4.3 mm (.18 in) diameter has been selected. Analysis has shown that, with the use of a heavy rubber bungee near the surface float and with the electromagnetic cable laced to it in bights, the concept of using a surface buoy is feasible. Both configurations satisfy all the mooring requirements from the hydrodynamic standpoint.

The components that are included in the electronic and sensor system are shown in Figure 4. The central ADOM processor with its data memory and power pack form the central electronic assembly. The segmented cable has terminations to allow the insertion of individually calibrated sensors. Above the central processor is either an acoustic telemetry assembly or a sensor/data cable to a surface float. Both options are currently being considered. The electronic assembly of processor, data memory and power pack is housed in a pressure housing in the ADOM subsurface buoy.

Based upon the progress to date, the following actions, analyses, and investigations are necessary in the continuation of the ADOM Feasibility Study (includes open ocean and ice covered ocean suspended systems). For the open ocean system, the planned actions during 1978 are as follows:

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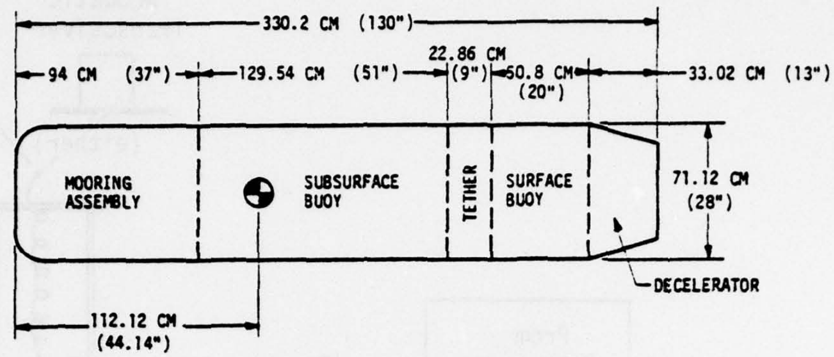
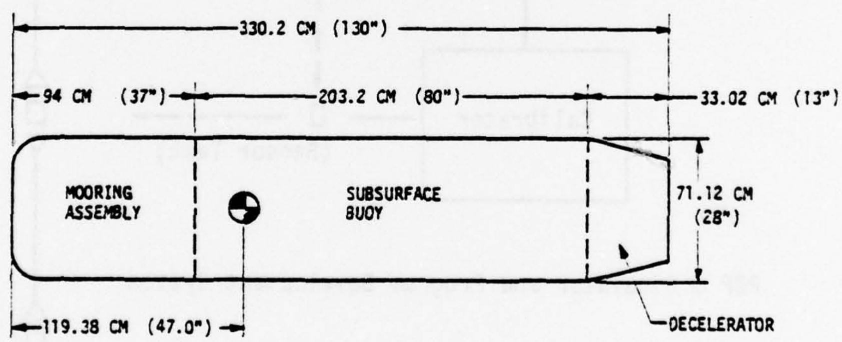


	WEIGHT KG (LBS)	BUOYANCY KG (LBS)
ANCHOR	634.9 (1,400)	-
BUOY	279.4 (616)	247.6 (546)
TETHER	22.7 (50)	-
SURFACE BUOY	50.3 (111)	156.5 (345)
DECELERATOR	90.7 (200)	-
	1078.0 (2,377)	404.1 (891)



	WEIGHT KG (LBS)	BUOYANCY KG (LBS)
ANCHOR	634.9 (1,400)	
BUOY	383.2 (845)	443.5 (978)
DECELERATOR	90.7 (200)	
	1108.8 (2,445)	443.5 (978)

Figure 3. ADOM Configurations

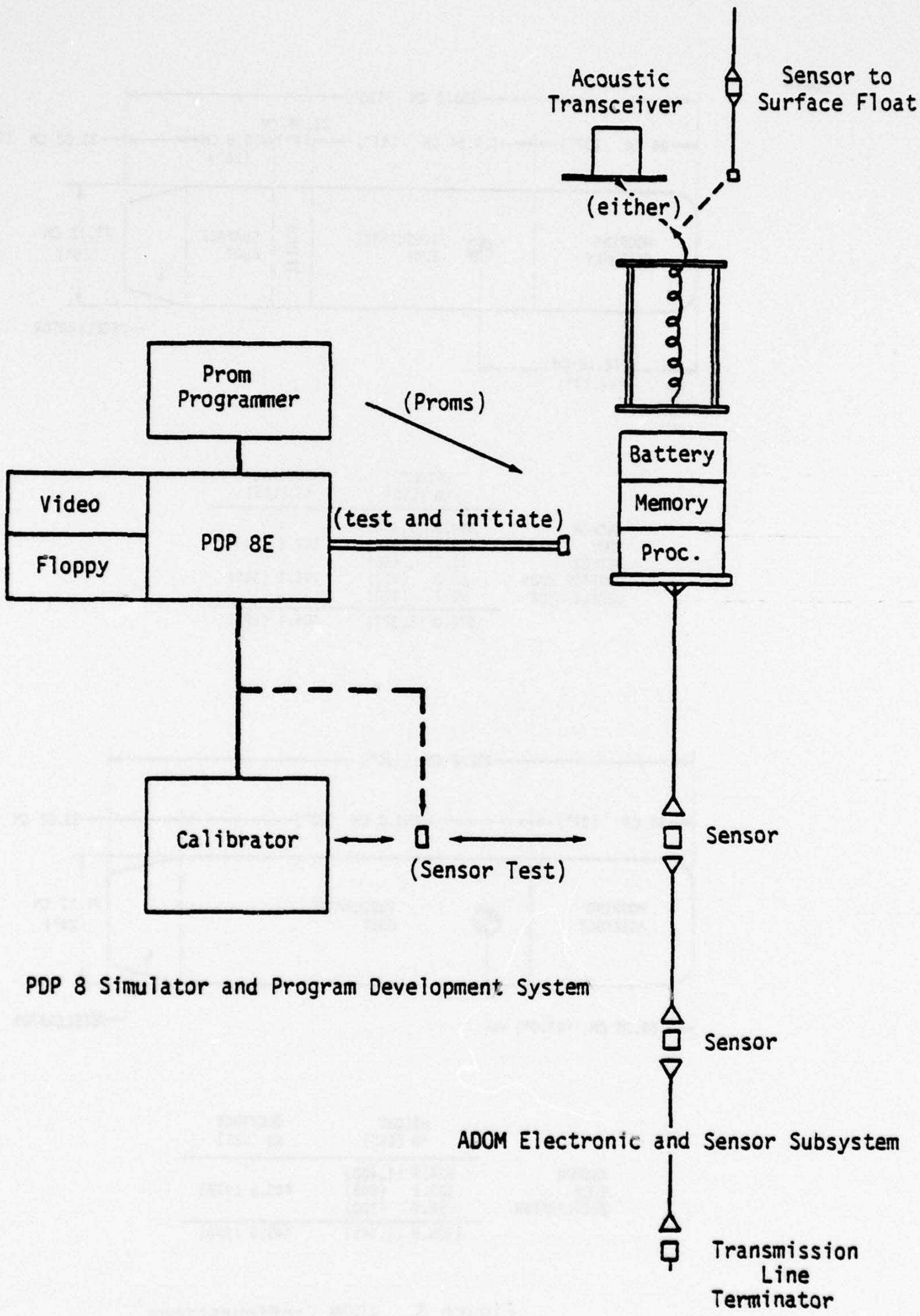


Figure 4. Content of the ADOM Electronic and Sensor System

a. Continue the hydrodynamic analysis to determine the need and feasibility of using antistrumming fairing and the antenna carrying capability of the surface buoy.

b. Develop the design of the subsurface buoy, surface buoy, tether, associated release mechanism and integrate with the anchor assembly so that the complete system can be specified.

c. Develop the processor and sensor array, and evaluate in a drifting buoy field test.

d. Develop and test other critical components such as cable payout mechanism, bottom finder, tether, and battery assemblies.

e. Refine cost estimates and perform cost tradeoff analysis.

For the ice covered ocean suspended system, the planned actions during 1978 are as follows:

a. A preferred system will be identified and evolved to a design concept with a fully defined view of strengths, weaknesses, costs and probabilities of success.

b. Upon completion of (a) above, the recommended penetration concept will be developed and prototyped for testing.

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SECTION I

INTRODUCTION

1.1 PURPOSE.

This document details the technology accomplishments in the Air Deployed Oceanographic Mooring (ADOM) program during 1977.

1.2 BACKGROUND.

Within the past decade, technology has progressed in oceanographic instruments, electronics and moorings to a level where reliable light-weight systems appear feasible. During this period, inflationary pressures, aggravated by spiraling fuel oil prices, have dramatically increased the operating costs of oceanographic vessels. Moreover, this trend is expected to continue in the foreseeable future. These factors, coupled with scientific requirements for ocean scale synoptic data, suggested a study to examine the feasibility of air launched, deep-ocean moored instrument platforms, ADOM.

A wide variety of scientific investigations can be pursued with air deployed oceanographic moorings which are configured to specific scientific requirements. Currently, aircraft are used to obtain spot measurements of sea surface temperature or temperature profiles. Since 1974, Navy P-3 aircraft have been used in the North Pacific Experiment (NORPAX), a major air/sea interaction experiment, to measure temperature profiles to 350 meters on a line between Adak and Honolulu and recently extended to Tahiti. These measurements were made by dropping expendable bathythermographs (AXBT's) from the air. Also, in the Western Pacific, P-3 aircraft recorded, in a similar manner, upper ocean temperature profiles before and after the passage of a typhoon. Because of their great speed advantage over surface vessels, aircraft have provided scientists with the ability to obtain synoptic data. Although present air deployable techniques fulfill many operational needs, future requirements stress long term measurements.

A number of important oceanographic studies could also be accomplished in an efficacious manner by deploying oceanographic moorings through the polar sea ice from long range aircraft. These studies would involve the air-ice-sea interaction and the mixing of Arctic Ocean water, and would prove to be a very important adjunct to our understanding of the circulation and dynamics of the Arctic Ocean.

Hence, three important benefits are realizable from an ADOM system:

a. Lower final data costs from effective use of aircraft.
b. Quick-response capability for the study of rapidly developing phenomena.
c. Applicability to areas which are difficult to access, notably the Arctic, Antarctic and Southern Oceans.

A progress report of the ADOM program was published in August 1977. It provided a summary of the technology progress of ADOM to that time. The remainder of this document will be devoted to recapping that progress and providing new information that has been developed since that time.

1.3 PROJECT ORGANIZATION.

The ADOM Feasibility Study is being conducted under the direction of Lt. Tom Christensen, CEC, USN, Ocean Science and Technology Division, Ocean Technology Program (Code 485), Office of Naval Research. The project was divided into technology areas as follows:

a. Open ocean moored system:
   (1) Mooring Mechanics - Mr. R. Walden, Woods Hole Oceanographic Institution
   (2) Hydrodynamics - Mr. L. Bonde, EG&G Washington Analytical Services Center, Inc.
   (3) Aero Mechanics - Mr. L. Markushewski, Naval Air Development Center

(4) Electronics - Dr. E. Softley, Ocean Electronic Applications, Inc.

b. Ice covered ocean system:

(1) Mooring Mechanics - Mr. R. Walden, Woods Hole Oceanographic Institution

(2) Ice Mechanics - Mr. L. LeSchack, Development and Resources Transportation Company and Dr. Robert Corell, University of New Hampshire

(3) Hydrodynamics - Mr. L. Bonde, EG&G Washington Analytical Services Center, Inc.

(4) Aero mechanics - Mr. L. Markushewski, Naval Air Development Center

(5) Electronics - Dr. E. Softley, Ocean Electronic Applications, Inc.

c. Scientific Advisory Committee:

Dr. D. Paskausky - Office of Naval Research

Dr. K. Hunkins - Lamont-Doherty

Dr. T. Sanford - Woods Hole Oceanographic Institution

Dr. L. Johnson - Office of Naval Research

1.4 SCIENTIFIC REQUIREMENTS.

Tables 1-1 and 1-2 present the scientific requirements for the open ocean and ice covered ocean ADOM. These were formulated by the scientific advisory committee shown in Section 1.3 and provided an independent starting point for the ADOM study.

Examples of recent and proposed future studies in the open ocean (Heinmiller et al 10th Annual Conference, Marine Technology Society Proceedings, September 23, 1974) include:

a. Heat exchange and quasi-permanent current systems: time scales - seasonal to annual (examples - NORPAX, PROJECT HEATFLUX)
b. Mesoscale eddies: time scales - weekly to annual (examples - MODE, POLYMODE, NORPAX, AIDJEX)
c. Mixed layer fronts and atmospheric forcing: time scales - daily to seasonal (examples - GATE, NORPAX, ISOS, INDEX, JASIN, AIDJEX, CUEA, MODE)
d. Internal waves and other temporally rapid fluctuations: time scales - minutes to weeks (examples - IWEX, JWEX, MILE, various acoustical experiments)

The various environmental processes which occur in the oceans are interdependent and so too are the scientific programs which address them. The end goal of all these programs is the prediction of real time ocean variability. Therefore, these models need to be derived from data sampling which is rapid enough to avoid aliasing, and of sufficient duration to measure the larger time scales as in heat exchange work.

Similarly, the Arctic waters have certain recognized basic phenomena. As the Atlantic and Pacific water masses approach the Arctic Ocean and spread throughout it, there is a mutual exchange of thermal and chemical properties. This exchange is influenced by seasonal fluctuations in the Arctic atmosphere as well as in the Atlantic and Pacific.

Underneath the ice, there is a mixed layer of water which is a reservoir of heat and less saline water. The characteristics of this mixed layer are strongly influenced by seasonal variations. In addition, the interaction of the three oceans, to some extent, cause mesoscale baroclinic eddies between depths of 50-300 meters and 10-20 kilometers

in diameter to spread throughout the Arctic. The maximum orbital speeds within these eddies is about 50 centimeters/second and occurs at a depth of about 150 meters. Scientific requirements for the ice covered ocean system cover the dynamical properties of heat exchange, mesoscale eddies, and mixing.

TABLE 1-1. OPEN OCEAN SYSTEM SCIENTIFIC REQUIREMENTS

	Heat Exchange	Mesoscale Eddies	Mixed Layer
Temperature (°C)	.001 - .01	.001 - .01	.001 - .01
Conductivity (mmho/cm)	±.01	.01	.01
Depth Accuracy (m)	±1	±1	±1
Currents (cm/s)	±1 (useful)	±1 (important)	±1 (vital)
Wind Speed or Sea State	--	useful	vital
Geographical Position Accuracy (km)	±10	±2-5	±1
Known Location (km)	±1	±1	±1
Grid Spacing (km)	500	50	.5-500
Number of Levels	20	20-30	20-30
0-200 m	every 20 m	every 50 m	20 (non-uniform distribution)
200-1000 m	every 100 m	every 100 m	10
below 1000 m	useful	every 200 m	100
Number of Moorings	2000 global	50-100	100
Frequency of Data Transmission (1)	Monthly	Weekly	Weekly
Duration (Yr)	1-2	1-2	1

(1) Assumes that near real time use of the data is required for models or failure detection.

TABLE 1-2. ICE COVERED OCEAN SYSTEM SCIENTIFIC REQUIREMENTS

	Heat Exchange	Mesoscale Eddies	Mixed Layer
Temperature (°C)	±.1		±.01
Conductivity (mmho/cm)	Valuable, but not necessary		±.01
Depth (Maximum) (m)	1000	300	
Depth Accuracy (m)	1% (1/2%, if possible)		1% (1/2%, if possible)
Current (cm/s)	Valuable, but not necessary	Necessary (Savonious Rotor O.K.)	
Wind Speed	Valuable (Barometer O.K.)	Valuable (Barometer O.K.)	Valuable (Barometer O.K.)
Geographical Position Accuracy (km)	10	±2	5-10
Known Location (km)		±2	
Grid Spacing (km)		5-10	400
Number of Moorings	12	50-100	25
Sampling Rate	Sufficient to obtain mean	10 minutes	10 minutes
Frequency of Data Transmission	Weekly	Weekly	Less than 1 year
Duration (yr)		1-2	1-2

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SECTION II

FINDINGS

2.1 GENERAL.

This section presents the findings of the ADOM Feasibility Study. Two mooring systems were investigated to meet the specific requirements of an:

a. open ocean system, and
b. ice covered ocean system.

Both systems are configured to measure temperature, conductivity, and pressure; however, the system design will maintain the flexibility to add additional sensors, when proven. A description of each system, the alternatives considered, and the rationale for selection of a preferred course of action are presented below. The following factors were considered:

a. hydrodynamic performance of both the open ocean and ice covered ocean systems, and factors affecting the performance, by parameter analysis;
b. the sensor and electronic system architecture and its development for optimum performance and weight;
c. compatibility with a service aircraft (P3) and performance during launch; and
d. need for auxiliary equipments to deploy and interrogate the system.

2.2 OPEN OCEAN SYSTEM.

The open ocean system, Figure 2-1, essentially is an instrumented mooring. The electronics and power supply are located in a subsurface buoy. The sensor array is in the upper 1500 meters of the mooring line. Data retrieval is by acoustic link to an independent drifting sonobuoy or through a tether to a surface buoy. The use of an acoustic link

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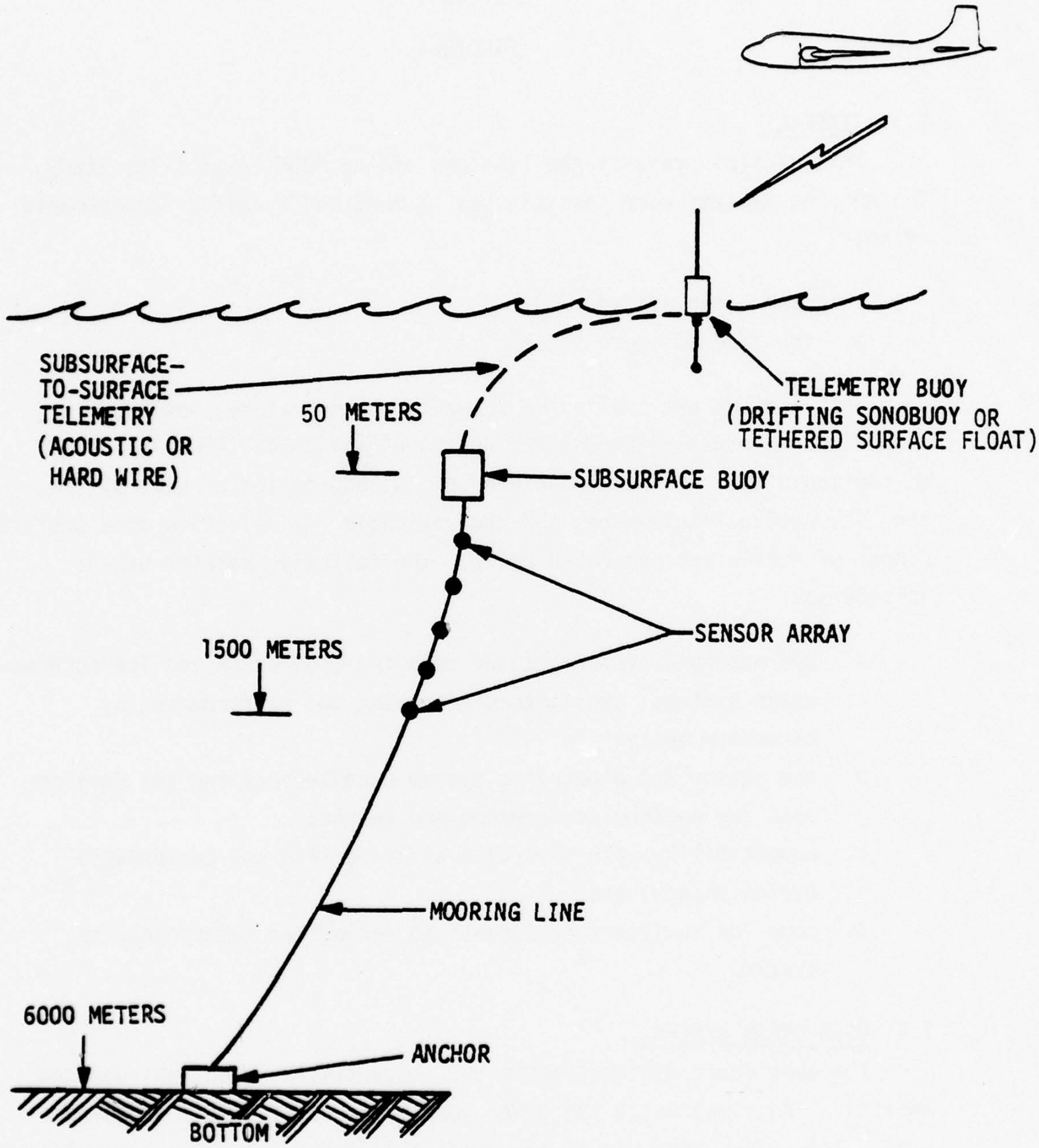

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Figure 2-1. Open Ocean Moored System

allows the entire mooring to be underwater at all times, escaping the most severe environmental forces. In the tether concept, the data are transmitted from a surface float tethered to the subsurface buoy. This eliminates the electronic complexity of the underwater acoustic transmitter, but requires the mooring to withstand wave and current action near the surface. In both cases, final data transmission is through a radio frequency link to an aircraft, or to a satellite when using the surface buoy.

The engineering parameters for the open ocean ADOM and a discussion of each of the subsystems are presented below.

2.2.1 ENGINEERING PARAMETERS FOR THE OPEN OCEAN ADOM. Table 2-1 presents the engineering parameters for the open ocean ADOM. In addition, current profiles for the operational and survival conditions are shown in Figure 2-2. The engineering parameters have been derived directly from the scientific requirements with the addition of known ocean characteristics. The current profiles represent a summary of the general experience of the ADOM team (including oceanographers) with considerable attention to previously formulated engineering requirements for other systems.

While a detailed examination of the compatibility of the ADOM system with the P3 aircraft will be given later, certain basic characteristics of the ADOM, as an aircraft store, are summarized in Table 2-2. These characteristics were used as primary factors in computing the hydrodynamic performance of the system.

2.2.2 HYDRODYNAMIC PERFORMANCE. The mooring subsystem is composed of the buoys, mooring assembly and decelerator assembly. Figure 2-3 presents two configurations for an open ocean ADOM, with and without a surface buoy.

TABLE 2-1. ENGINEERING PARAMETERS FOR OPEN OCEAN ADOM

Sea State	
Operational	4
Survival	6
Water Depth (m)	6000
Measurement Depth (m)	50 - 1500
Sensor known depth accuracy (m)	$\pm$ 1
Number of Sensors	40
Sensor Spacing (m)	20 to 200*
Temperature Accuracy (°C)	.001 - .01
Sampling Rate (minutes)	10 to 60*
Frequency of Data Transmission (weekly)	1 to 4
Operational Life	Longer than 6 months

* Adjustable prior to packaging

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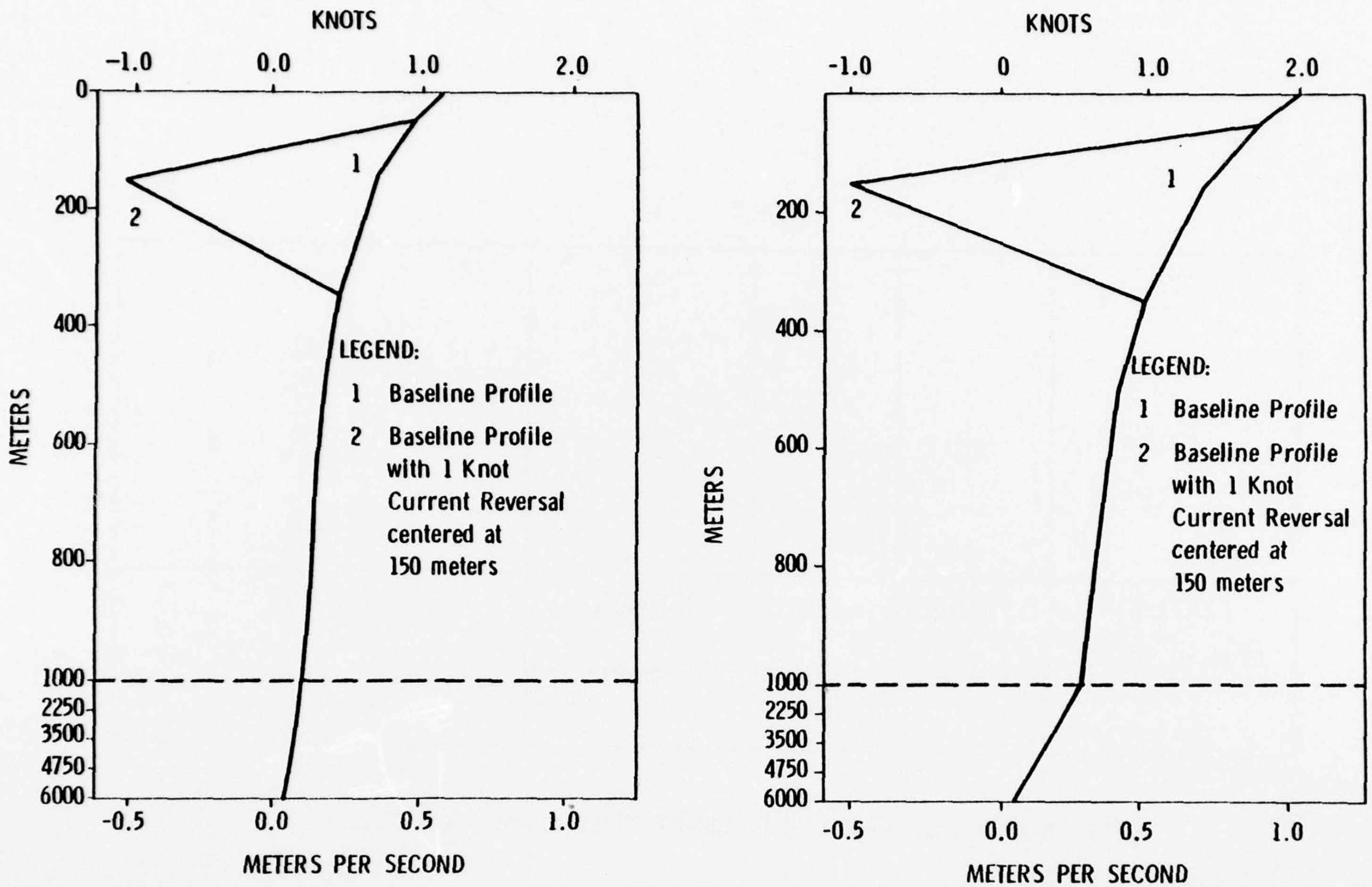

OPERATIONAL CURRENT PROFILE

SURVIVAL CURRENT PROFILE

Figure 2-2. Open Ocean Operational and Survival Current Profiles

TABLE 2-2. BASIC STORE CHARACTERISTICS FOR P3C COMPATIBILITY

CONFIGURATION	NUMBER			
	BOMB BAY	WING	TOTAL	TOTAL PAYLOAD Kg (lbs)
L <335.28 cm (132 in) D < 71 cm (28 in) W <1111.1 Kg (2450 lbs)	0	6	6	6666.7 (14,700)

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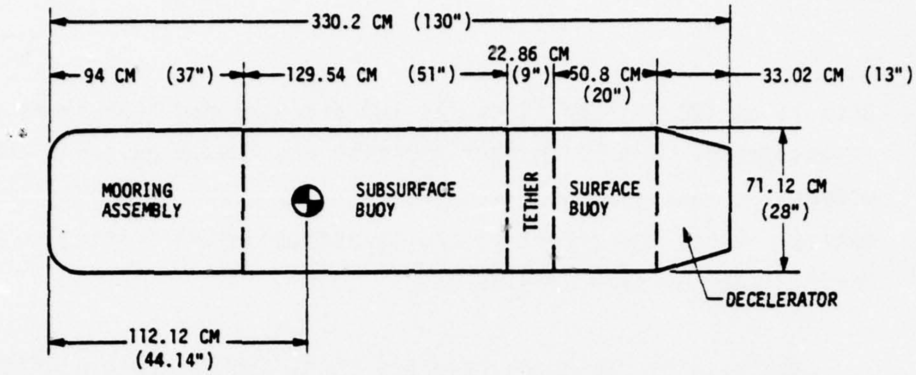

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ANCHOR	634.9 (1,400)	-
BUOY	279.4 (616)	247.6 (546)
TETHER	22.7 (50)	-
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DECELERATOR	90.7 (200)	-
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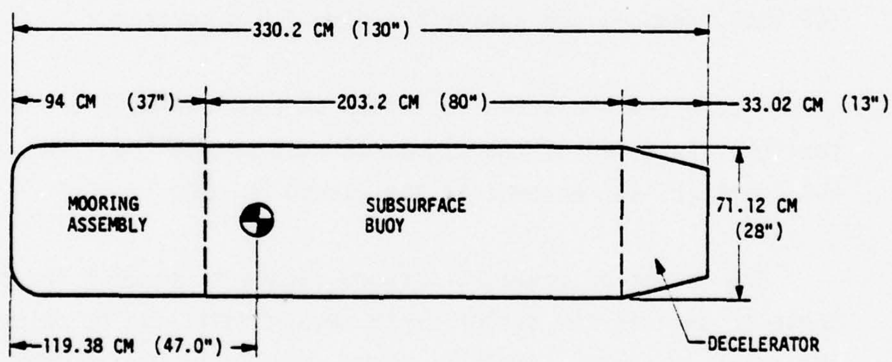

	WEIGHT KG (LBS)	BUOYANCY KG (LBS)
ANCHOR	634.9 (1,400)	
BUOY	383.2 (845)	443.5 (978)
DECELERATOR	90.7 (200)	
	1108.8 (2,445)	443.5 (978)

Figure 2-3. ADOM Configurations

Both 71 cm (28 in) and 54 cm (21 in) diameter configurations were investigated. The 71 cm configuration was chosen as being the most effective. Analyses were made for various sizes of Kevlar and steel cables. Also, the effect of adding antistrumming fairing to reduce drag coefficient has been considered.

The results presented here are for a single cable configuration with a steel, double armored, single conductor sensor cable 4.3 mm (.18 in) diameter and a jacketed Kevlar lower cable of 4.3 mm (.18 in) diameter The buoy performance is measured by the dip, i.e., the vertical excursion from the no current position of the subsurface float assembly.

Table 2-3 shows that suppressing cable strumming reduces subsurface buoy dip by 23 to 24 percent in the operational profile and 18 to 19 percent in the survival profile. In contrast, increasing the net buoyancy of the subsurface buoy 4.6 percent, by reducing its payload 200 Newtons (45 lbs), reduces the subsurface buoy dip 8 percent.

Figure 2-4 shows the variation of buoy dip with current profile intensity. Part (a) of the figure corresponds to the first column in Table 2-3; part (b) corresponds to the second column.

The number of pressure sensors needed to predict the profile of the cable to satisfy the sensor depth requirements can be determined from the above analysis. At least three gages will be required to predict the sensor depth to within 1 meter accuracy.

A computer model of a two-stage ADOM mooring with a tether line to link the surface float with the main subsurface buoy was developed. Appendix A presents the results of the analysis of the mooring using the

TABLE 2-3. SUBSURFACE BUOY DIP

Net Buoyancy		
Surface Buoy (awash)	0	0
Tether Buoy	0	0
Subsurface Buoy Kg f	444	464
Newtons	4350	4550
(lb f)	(978)	(1023)
	DIP (Meters)	DIP (Meters)
Case I: Operational Profile		
(a) E-M Cable Strumming $C_N = 1.8$	40.	37.
(b) Strumming suppressed $C_N = 1.2$	31.	28.
Case II: Survival Profile		
(a) E-M cable strumming $C_N = 1.8$	239.	226.
(b) Strumming Suppressed $C_N = 1.2$	195.	183.

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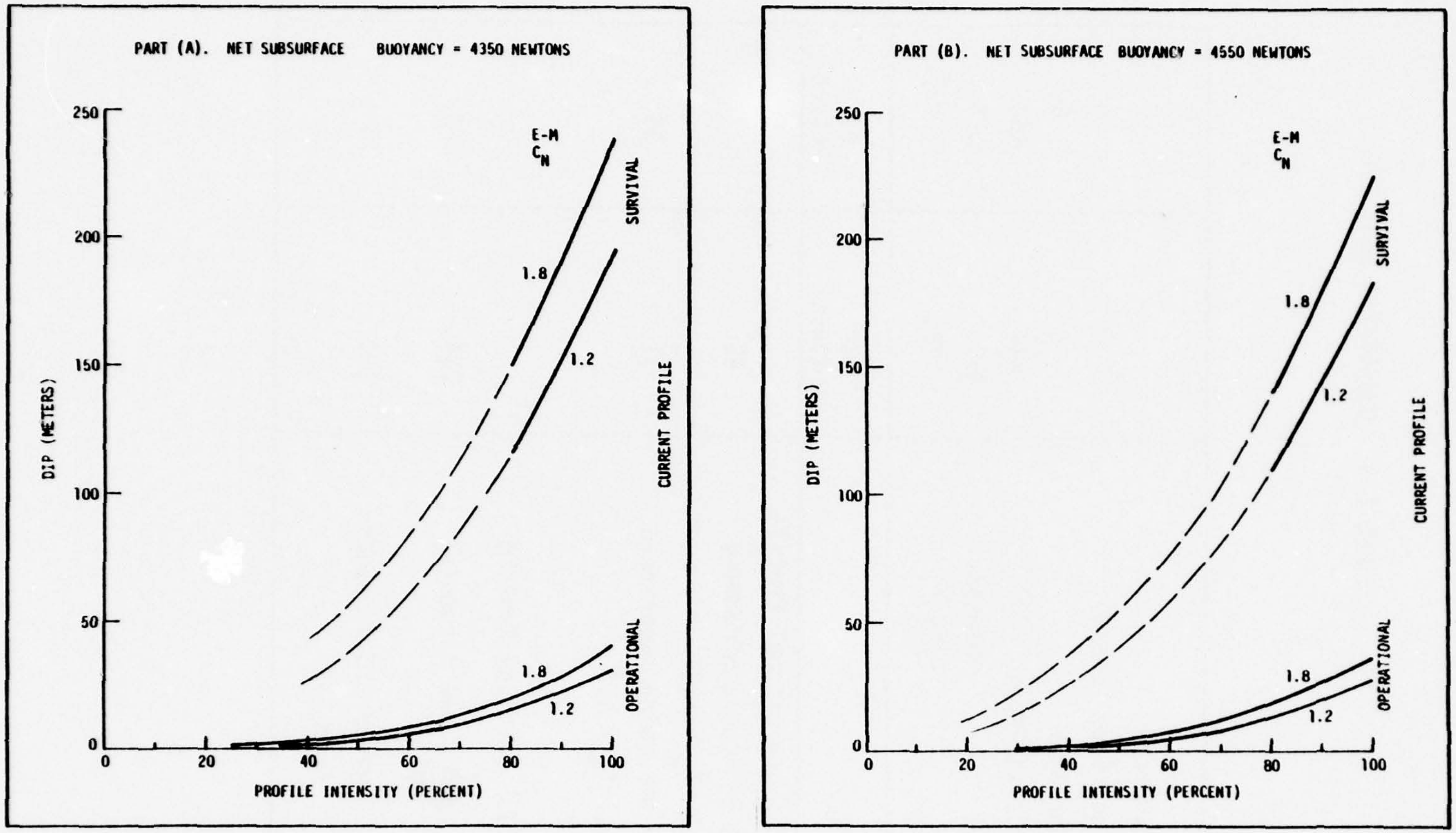

Figure 2-4. Subsurface Buoy Dip vs Current Speed

model. It was determined that, with the use of a heavy rubber bungee near the surface float and with the electromagnetic cable laced to it in bights, the concept of using a surface buoy was feasible. Using a tension variation fraction of 0.15 as the design criterion, the recommended ADOM surface buoy and tether parameters are:

Float Diameter	71.0 cm (28 in)
Float Length	50.8 cm (20 in)
Bungee Diameter	23.6 mm
Bungee Length	10.0 m
Bungee Resonant Period	9 s
E/M Pennant Length	39.6 m
Total E/M Length in Tether	79.6 m
Subsurface Buoy Dip	
Operational	18. m
Survival	260. m
Surface Float Depth	
Survival	242. m

2.2.3 ELECTRONIC AND SENSOR SUBSYSTEM. The components that are included in the electronic and sensor system are shown in Figure 2-5. The central ADOM processor with its data memory and power pack form the central electronic assembly. The segmented cable has terminations to allow the insertion of calibrated sensors. The assembly is terminated by an additional component which provides cancellation of traveling waves in the cable and allows determination of the voltage drop along the cable. Above the central processor is either an acoustic telemetry assembly or a sensor/data cable to a surface float. Both options are currently being considered.

The electronic assembly, which consists of a processor, data memory and power pack, can be housed in an eight inch diameter aluminum cylinder which can be made into a separate pressure housing of the ADOM buoy. With this housing, the electronic and sensor system can be considered to be a complete mechanical and electrical subsystem ready to be integrated into ADOM.

2.2.3.1 PROCESSOR. The Intersil IM 6100 CMOS microprocessor was chosen for the design. The microcomputer is shown schematically in Figure 2-6. The assembly consists of seven boards which plug into a computer type backplane or motherboard. The seven boards and their functions are:

AµP	Microprocessor, connection to computer
ACL	Real time clock, interval clock
ADA	Data acquisition, sensor operation
APR	PROM, permanent program stage
ARA	RAM, working program
ADX	External data storage interface
ATX	Data telemetry

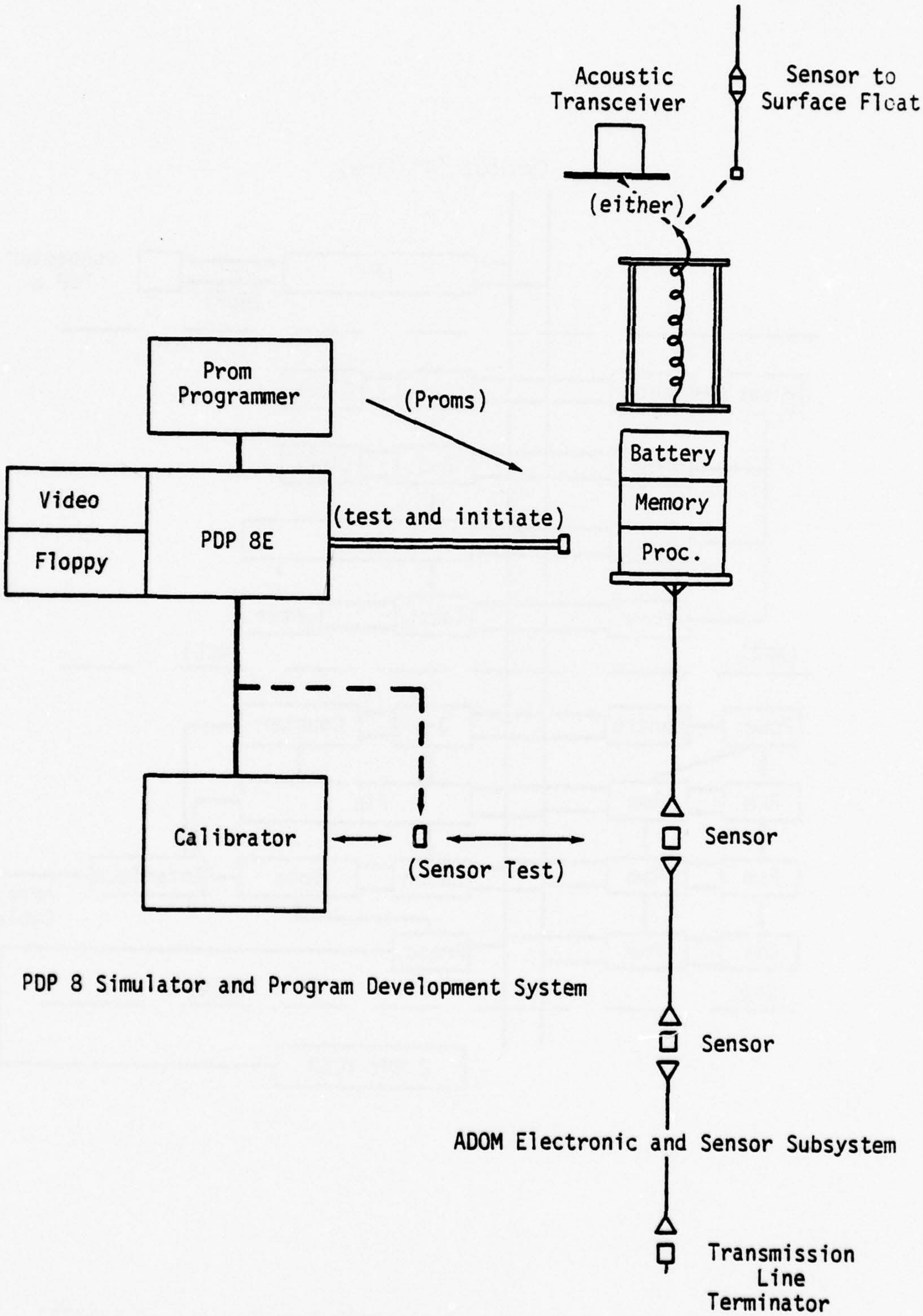

Figure 2-5. Content of the ADOM Electronic and Sensor System

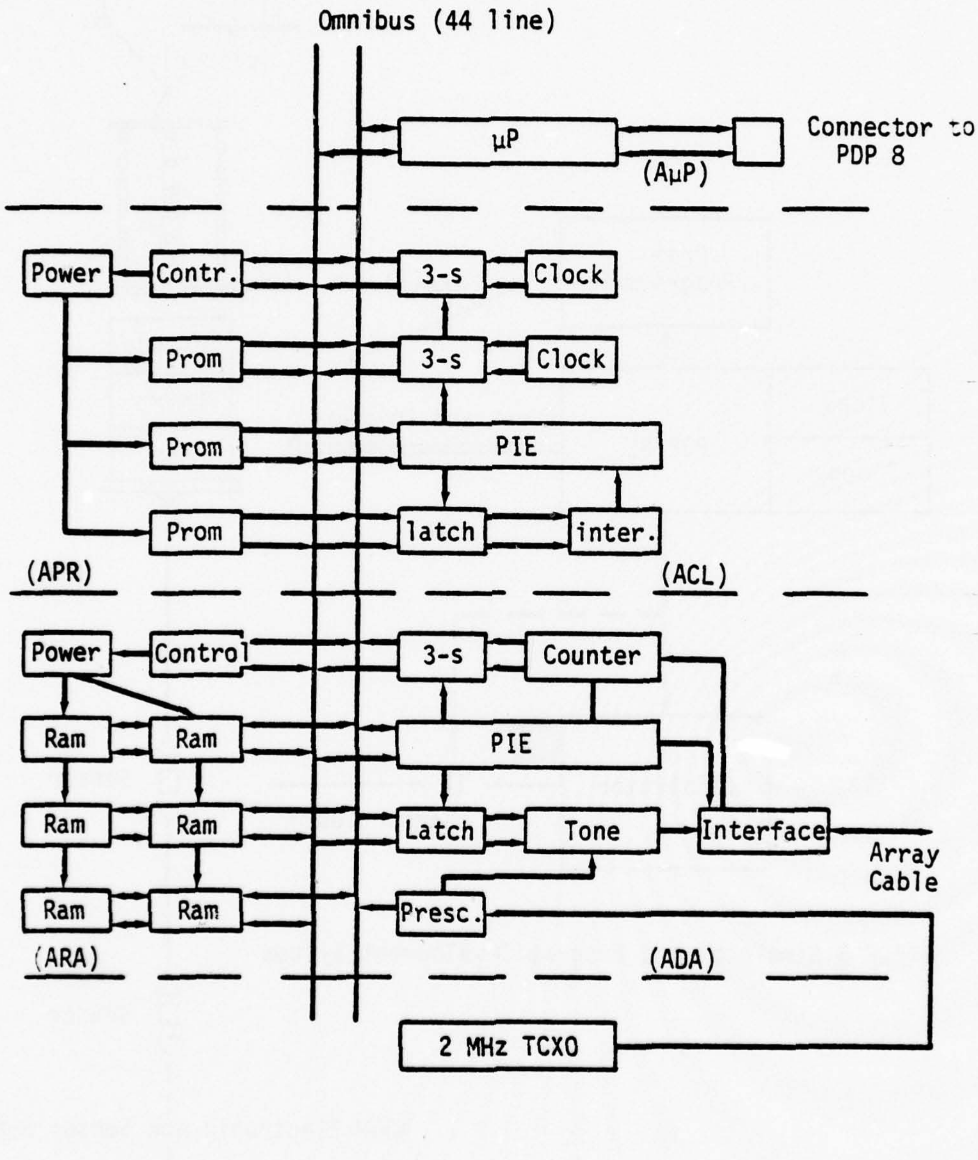

Figure 2-6. Schematic of the ADOM Computer (as of 1/1/78)

Each board uses the same pin connection to the motherboard, and therefore, can be placed in any position.

In addition to these seven boards, an external temperature compensated crystal oscillator (TCXO) provides a 2MHz clock which is used for all timing functions as well as the generation of command frequencies. Figure 2-7 shows a breadboard assembly of the ADOM processor. The data acquisition board (ADA) is shown in the foremost position. Also included are the microprocessor (AμP), the PROM (APR) boards, and the clock board (ACL). This system is currently operating.

Operation of the ADOM computer can be programmed and easily changed. The basic operation consists of several steps. The microprocessor, for much of the time, is idle with only the clock board powered. When a preset interval is completed, the processor is powered and reset. It, in turn, powers the PROM board and bootstrap loads the program from the PROM into RAM memory. Typically, 100 ms will allow transfer of a 512 word program. Here, bipolar PROMS can be used since they are enabled for a short time only.

The computer now acquires data from the sensor array. Approximately three sensors per second can be interrogated. The time would also be read from the clock board at both the beginning and end of the data acquisition cycle.

Data manipulation would then take place. It is likely that corrections to the data for voltage drop along the cable will be desirable to achieve better sensor accuracy. Typical data manipulation times will be 500-600 ms. The data will be transferred to storage.

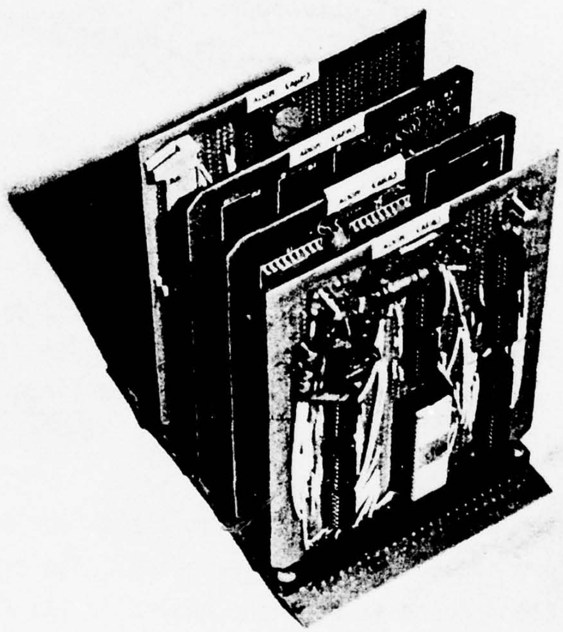

Figure 2-7. ADOM Processor in Breadboard Form

The duration of this will depend on the number of sensors for a thirty sensor system. This will be about 120 ms. The processor will determine the interval to the next data acquisition cycle and store this in the clock board and then power down.

It is possible to determine the power cycle for the processor, and this cycle is shown in Figure 2-8. This information is also used to determine the loading on the individual battery cells which comprise the power pack.

2.2.3.2 <u>INTERROGATION TECHNIQUE AND THE TEMPERATURE SENSOR.</u> A single conductor cable with double armor return will be used for the sensor array. This must carry power and interrogation signals to the sensor and data from the sensors to the processor. Since the basic measuring standard is a crystal oscillator in the processor, it is convenient to use timed pulses for the data and crystal derived frequencies for the interrogation.

It also allows the design of a system that will tolerate considerable signal attenuation in the cable. This is important since, if it is desirable to include a large number of sensors in the array, the voltage decay along 1500 meters of cable can be considerable.

The system used employs a D. C. voltage for the power. Interrogation signals consist of two, three or four pulsed tones in the range of 700 to 1600 Hz. These are on the order of 400 mV p/p at the processor and would expect to attenuate to 200 mV at the lowest sensor.

Sensor sensitivity is set to be 100 mV, and if the sensors respond to the interrogation, two pulses, of duration 15 μs and with separation of 20 to 120 ms, are sent in reply. In general, the first of these will occur within the last tone. Figure 2-9 shows the cable signals for a three tone system.

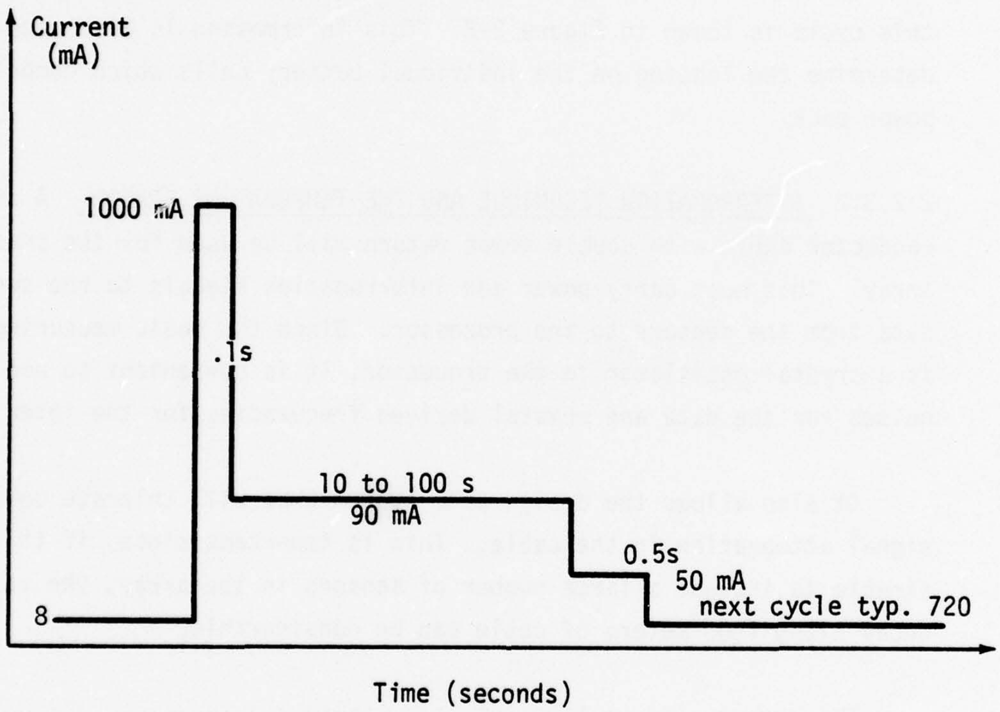

Figure 2-8. Example of Typical Processor Power Cycle

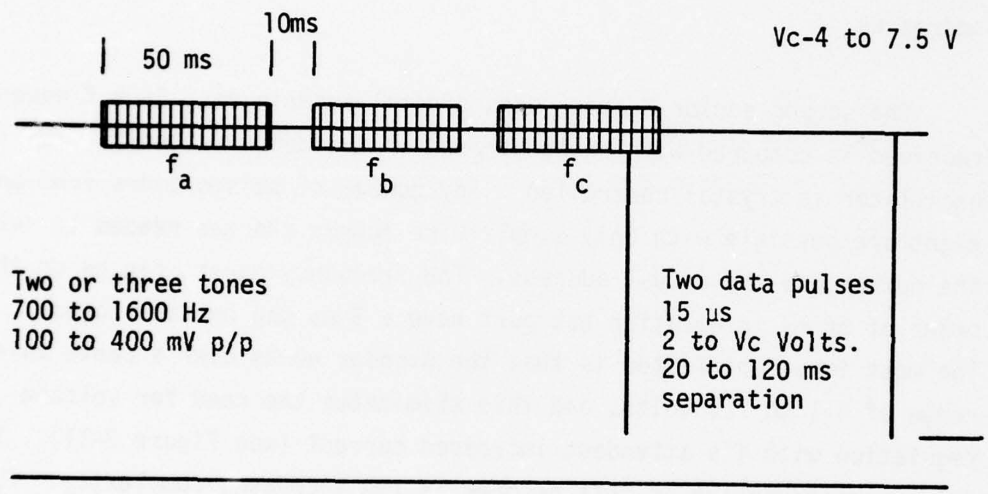

Figure 2-9. Typical Interrogation Signals in Array Cable

Two types of sensor and command decoders have been designed and evaluated in breadboard form (see Figure 2-10). The first of these uses two phase locked loops to recognize each of two input signals. It was found that a 100 ms tone pulse was needed. Of more significance is the fact that these phase locked loops are highly sensitive to supply voltage and this necessitates voltage regulation. This results in an undesirable voltage/current relationship and a limited voltage operating range (see Figure 2-11). By nature of the system, the two frequencies cannot be equal. With eight fundamental frequencies, there are 56 unique sensor addresses.

The second sensor decoder uses digital techniques. Each frequency received is compared with one generated in the decoder itself. The local oscillator is crystal controlled. Any number of pulsed tones from one to eight are possible with only simple wire jumper changes needed to select the number and the actual address. The frequency bursts can be on the order of 50 ms in duration but must have a 5 ms gap between tones. The most important factor is that the decoder works over a cable voltage range of 4.1 to 7.5 volts, and this eliminates the need for voltage regulation with its attendant increased current (see Figure 2-11). The primary disadvantage of this decoder is the increased complexity. Part count approximately doubled. However, the low cost of integrated circuits (I.C.s), the ability to prepackage some of the functions in custom I.C.s, and hence, reduce the part count, would probably minimize this objection. Table 2-4 summarizes the important characteristics of the two approaches.

The temperature sensor is quite simple. A 4528 CMOS one-shot uses a thermistor for the timing circuit. The resulting pulse is differentiated to provide timing pulses at the start and stop of the 4528 pulse. Accuracies on the order of 0.1C over the range 0-30C is achieved, and this becomes .01C with suitable correction for the supply voltage variation. An accuracy of .01C will meet the requirements stated in Table 1-1.

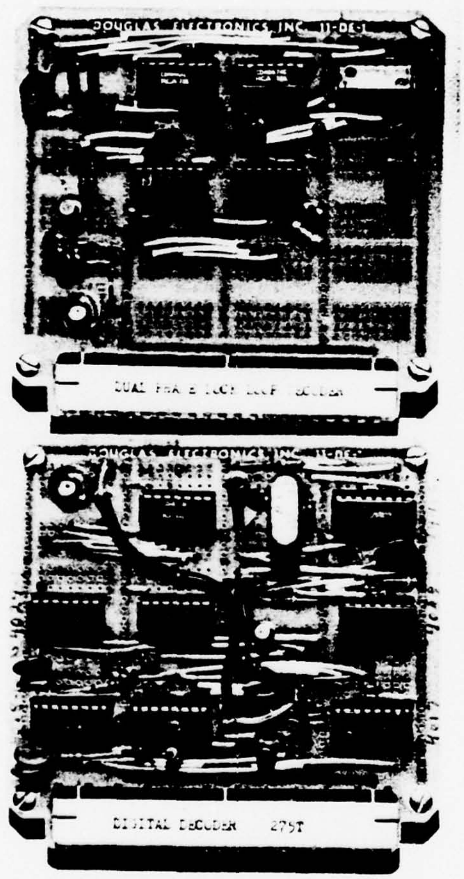

Figure 2-10. Dual Phase Lock Loop and Digital Decoder Breadboards

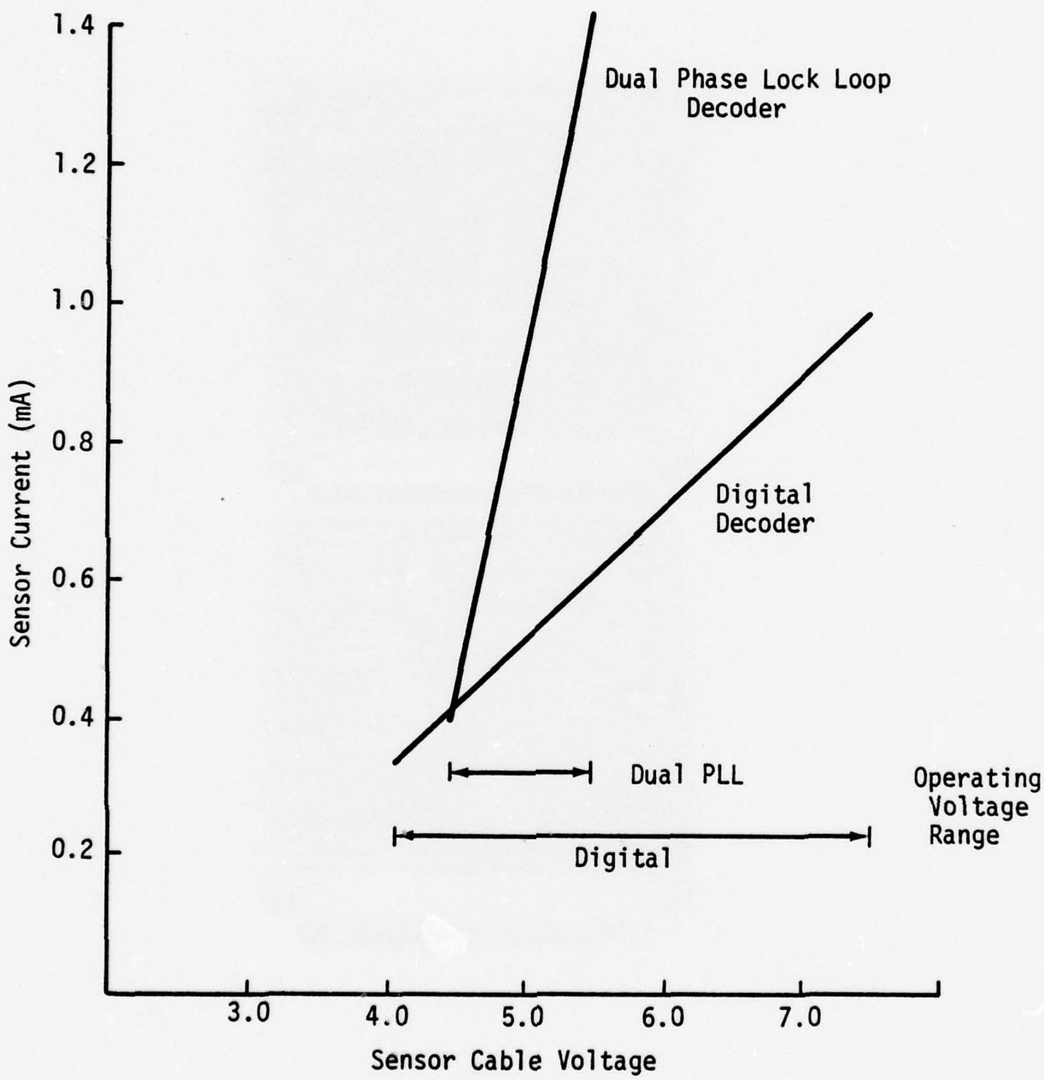

Figure 2-11. Comparison of Decoder Power Requirements

TABLE 2-4. COMPARISON OF SENSOR DECODER DESIGNS

	Dual Phase Lock Loop	Digital Decoder		
		N = 2	N = 3	N = 4
No. of Unique Addresses	56	64	512	4096
Data acquisition Time (ms)	430	250	370	490
Min. Cable Voltage (volts)	4.5	4.1	4.1	4.1
Max. Cable Voltage (volts)	5.5	7.5	7.5	7.5
Maximum No. of Sensors in 1500 m Cable (Power Limitation)	58	240	240	240
Cable Current For:				
50 sensors	32.7	18.6	18.6	18.6
100 sensors	---	40.9	40.9	40.9
(mA)				

2.2.3.3 SENSOR CABLE CHARACTERISTICS. It has been determined that the cables should be as small as possible. Cables on the order of 4.3 mm diameter were found to be typical. When the sensor characteristics are incorporated, two additional factors are important. The direct current (D.C.) resistance should be kept low and there must be limited attenuation at frequencies on the order of 30 kHz (data pulse risetime). The data pulse will be a maximum of about 120 ms, and with a count of 4096 (12 bits), the count frequency is 31 kHz. Hence, for the data pulse not to be distorted excessively, signal attenuations of less than 10 db over 1500 meters of cable must be achieved. Some sample cables have been considered. The critical characteristics of the cables being considered are given in Table 2-5.

The final choice will depend on a tradeoff of electrical performance and mechanical suitability.

The characteristics of the second cable in Table 2-5 have been used to determine the number of each type of sensor that it is possible to incorporate in a sensor array by consideration of the voltage drop down the cable. The criteria is that this voltage must be within the operating range shown in Figure 2-11. If the voltage is assumed to be at the low limit at the bottom of the cable, then the voltage at the top of the cable can be computed. Figure 2-12 demonstrates this fact. For the Dual PLL Decoder, it is possible to stack 58 sensors in the cable. With the digital decoder, over 240 sensors are possible.

It should be noted that, even though such a large number of sensors may not be required at any one time, the large capability reflects in higher tolerances when the sensor number is less than the theoretical maximum. The D.C. resistance of the cable is less critical and control of the cable supply voltage is also unnecessary.

TABLE 2-5. CRITICAL CABLE CHARACTERISTICS

Cable No.	Diameter (mm)	Break (kg)	Resistance (ohms/km)	Capacitance (pfd/m)
1	4.3	1077	50	157
2	4.7	1318	44	190
3	5.2	1864	35	229

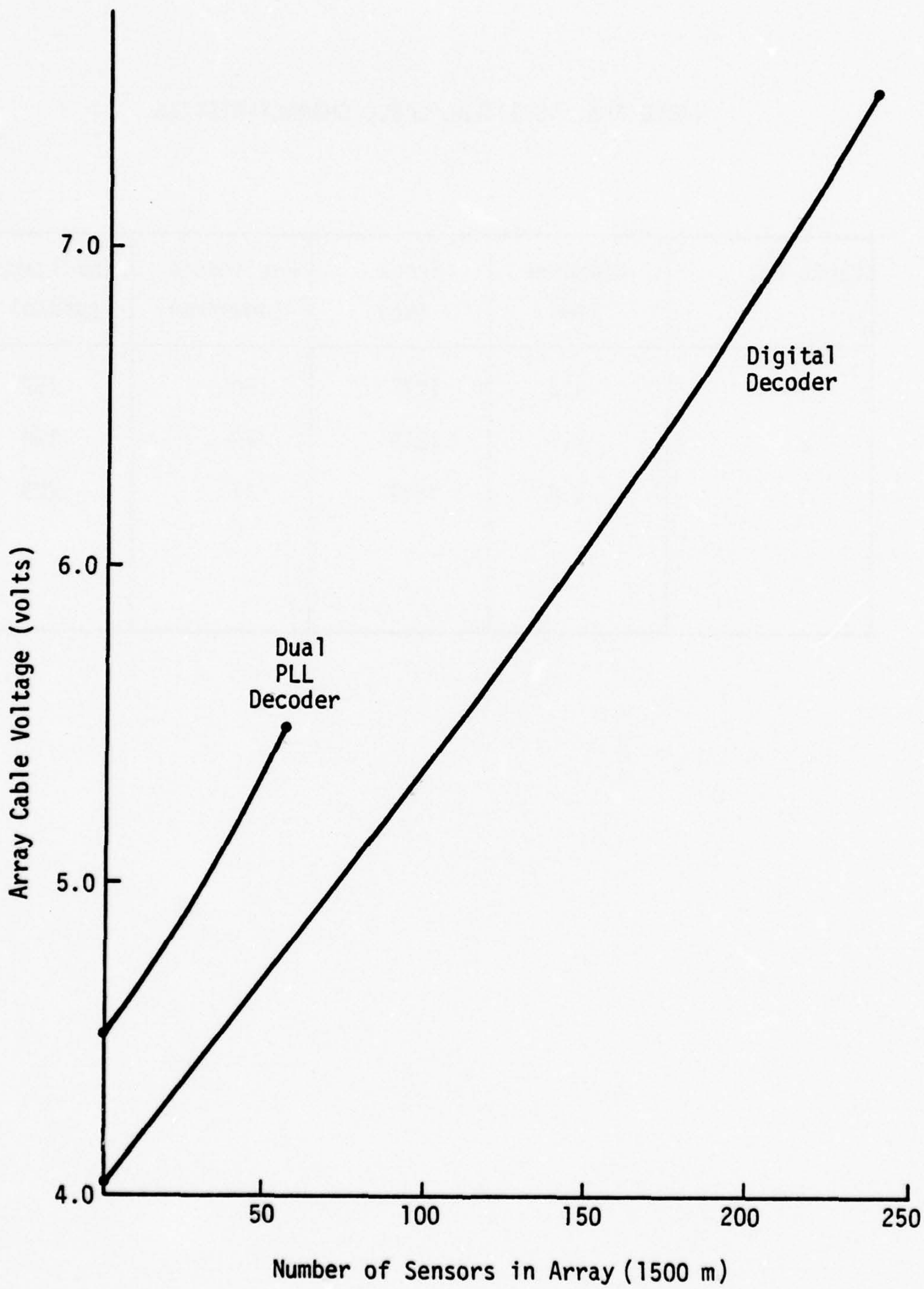

Figure 2-12. Cable Voltage as a Function of Number of Sensors

2.2.3.4 PROGRAM DEVELOPMENT. The development of microprocessor based hardware must be accompanied by simultaneous development of the operating software. Since custom designed peripheral hardware is key to the design, the software is most conveniently written in machine language. A PDP8 minicomputer was used for this programming, with the program elements stored on a floppy disc. Many higher order languages are available, such as FOCAL, BASIC, and FORTRAN, and they can be implemented as the task proceeds.

The only program element completed is that for the sensor data acquisition. The processor selects a sensor from a list stored in the computer and creates the command sequence. Data is obtained by counting a 31 kHz clock. If no data is obtained, the computer will make two additional attempts to obtain data, and if then not available, label the data as invalid. An additional refinement, not incorporated as yet, is to compare data words with those previously obtained to spot unreasonable changes. These can also be flagged.

2.2.3.5 BATTERY TESTS. Lithium organic batteries are the best currently available to meet the requirements. Of particular importance was the specific energy capability at low temperatures (-40C). Manufacturers' data was used. To confirm this data, to make a selection among the battery manufacturers, and to obtain voltage histories under typical loads, some low temperature battery tests have been initiated. A commercially available standard freezer was used. The controls were modified and extra insulation added. Instrumentation and a multiconductor cable have also been installed. Temperature measurements indicated -38C to -41C.

Three battery loadings are used. These correspond to the three battery packs in ADOM. They are:

a. Processor Battery,
b. RAM Battery (data retention), and
c. Telemetry Battery.

For RAM data retention, a steady cell current of 0.7 mA is used. The telemetry cycle consists of a current of 500 mA for 32 minutes duration.

To perform these cell loadings, a battery testing circuit is used. This circuit performs the loading cycles automatically. Data is read by a digital voltmeter (DVM) once per week and includes a telemetry cycle with voltage histories through the cycle. Voltages are also read throughout the processor cycle.

For comparison, data was also taken on cells at room temperature (20C to 22C). Two manufacturer's products were included in the test.

The telemetry data shows one interesting trend. After five cycles, corresponding to five months of normal operation, the battery voltages through the cycle increased slightly. Also, voltages through the first loading cycle were highly scattered and have become much less so after the initial cycle. This indicates the need for a burn-in period to stabilize the cell. Figure 2-13 shows a typical voltage reaction for several telemetry cycles.

2.2.3.6 <u>ACOUSTIC DATA TELEMETRY.</u> One of the data telemetry options is an acoustic data link to a sonobuoy on the ocean surface. This sonobuoy would relay the data via radio frequency (R.F.) link. The choice of acoustic frequency depends on the range and on the hardware. Calculations of the

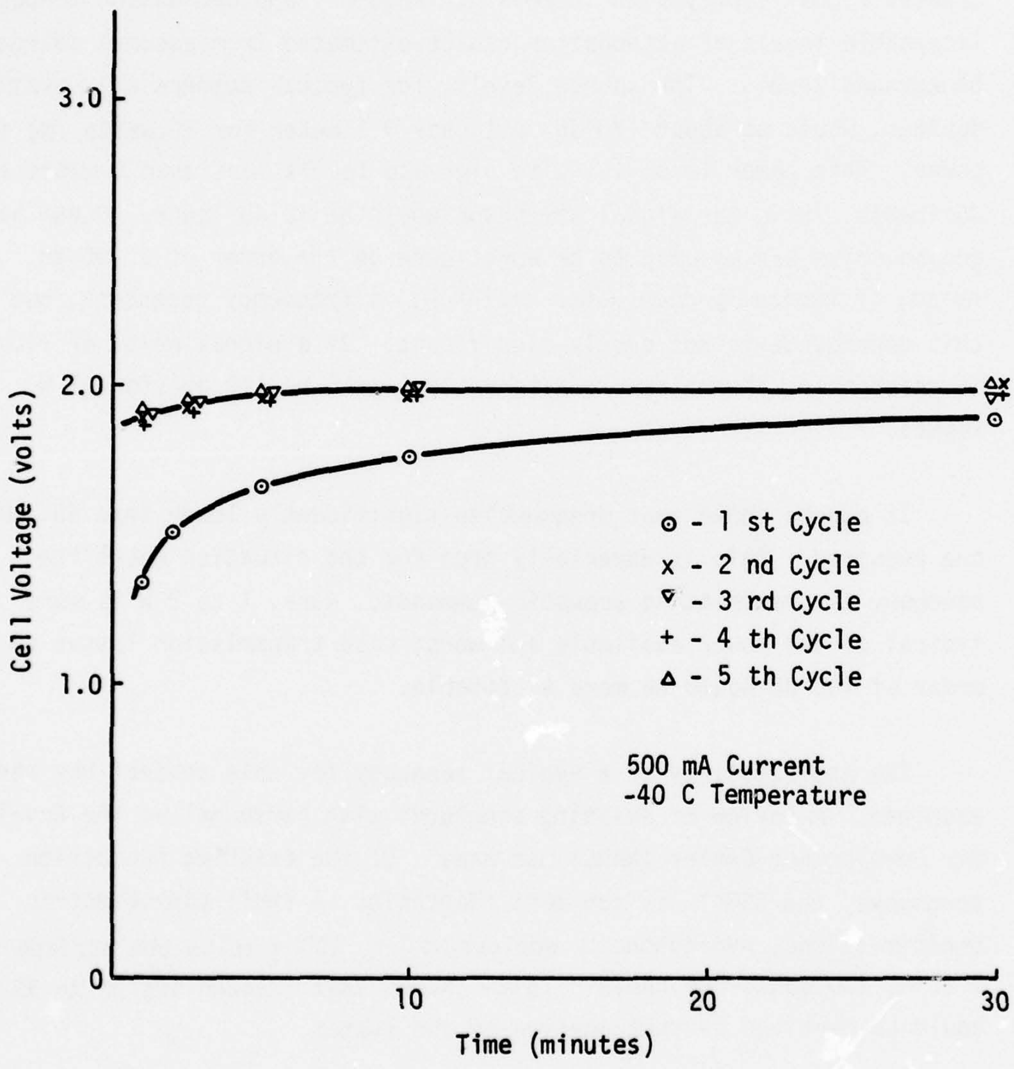

Figure 2-13. Lithium Cell Test Results (Telemetry Pack @ - 40 C)

signal loss for varying frequencies and seawater temperatures were made. A fully refractive ray was assumed to be present, and signal attentuation due to spherical spreading and absorption was assumed. Attenuation increased significantly with increasing frequency and decreasing temperature. Acceptable levels of attenuation can be estimated from assumed source and background levels. The source levels, for typical commercially available devices, would be about +70 db re 1 ubar @ 1 meter for 18 watts (W) input power. This power level is quite high and levels less than 5 watts are more desirable. Here, the signal strengths would be 10 db lower. Ocean background noise was assumed to be worst case on the order of a -50 db. This noise, if typically deep water ambience, is frequency dependent, but this dependence is not overly significant. If a signal noise of +10 db is reasonable, the allowable attenuation would be 110 db (for 18 W input).

It can be shown that frequencies significantly lower than 50 kHz are required. This is especially true for the situation where the sonobuoy is transmitting acoustic commands. Here, 1 to 2 W is more typical of the power available and worst case transmission losses on the order of 100 db would be more acceptable.

The applicability of a typical sonobuoy for this project has been examined. A review of existing sonobuoys with personnel at the Naval Air Development Center (NADC) was made. Of the existing production sonobuoys, the SSQ41 was the most adaptable. A small piezoelectric omnidirectional hydrophone is deployed 20 to 100 m below the surface on a thin, two conductor cable. Tests showed that frequencies up to 33 kHz could be received by that portion of the system.

Using hardware obtained from the SSQ41, a number of laboratory experiments were performed. It was found that an optimum system with

this hardware would use 25-30 kHz signals. Both NRZ and split-phase Manchaster signals were frequency modulated onto a 27.5 kHz center frequency. In addition, the SSQ41 hydrophone was adapted as a transmitter, and it was found that up to 6W of input power could be achieved using the SSQ41 seawater battery. In summary, it was possible to readily adapt the SSQ41, and the important parameters fitted the required system.

As a demonstration of the system and in order to determine the critical problem areas, an ocean test was performed in the Tongue-of-the-Ocean in July 1977. Several SSQ41B sonobuoys were obtained from the Naval Air Development Center (NADC) and adapted for the test. A coder/amplifier was designed and constructed and installed in two of the SSQ41Bs. This coder caused the transmission of a sequence of coded data. Frames of 32 words of data were sent. Each frame consisted of a synch word (16 bits) and 31 words of data (including a real time clock).

The transmission sequence was as follows:

250 Hz	NRZ
Silence	
250 Hz	NRZ
Silence	
250 Hz	Manchester
Silence	
250 Hz	Manchester

The sequence was repeated at 500, 1000 and 2000 kilobaud/second (KBS). The transmitter power was about 2 W in order to preserve the battery for the life of the test. The whole sequence was repeated for 8-1/2 minutes, with a 26 minutes off period.

A second group of SSQ41B sonobuoys supplied a set of receive hydrophones and amplifiers. A set of band pass filters was added. The signals were recorded on a Sangamo 14 track tape recorder. This assembly was portable and mounted in a small vessel (42 feet length overall (LOA)). In addition to the acoustic signals, the same data required was transmitted through the sonobuoy R.F. transmitter and received on board the vessel. This information was also recorded on a track on the tape recorder. By examining the acoustic signals relative to the R.F. signals, a value for the range of transmission could be achieved.

The experiment was performed in the Tongue-of-the-Ocean (TOTO). The transmitting sonobuoy was launched and an initial data sample taken. During each 26 minute silent period, the vessel was moved away from the sonobuoy. This was continued up to 2.2 km range. The recorded data was examined through a FM discriminator in the laboratory. Manual adjustment for signal strength was made. Bit error rates for data rates of 1 KBS and less were low, 1×10^{-4}. At 2 KBS, the error rate was higher, 5×10^{-4}.

Signal strengths are shown in Figure 2-14. They agree very well with predicted transmission losses. The background noise was high due to the need to run the vessel's generator.

2.2.3.7 SENSOR PACKAGING. The basic approach for sensor packaging uses a segmented sensor cable with terminals at the sensor locations. These terminals provide mechanical and electrical connections. To facilitate handling, the sensors are connected to the cable segments using a separate cap nut. The sensors can then be easily installed in a calibration bath and individually calibrated prior to assembly of the final cable.

The sensor assembly is nominally 25 mm in diameter and 50 mm in length. If the sensor is fabricated from a standard package of integrated circuits, this will increase somewhat (30mm dia x 7mm long). With fabrication from chips onto a substrate and encapsulated, the dimensions also can be reduced.

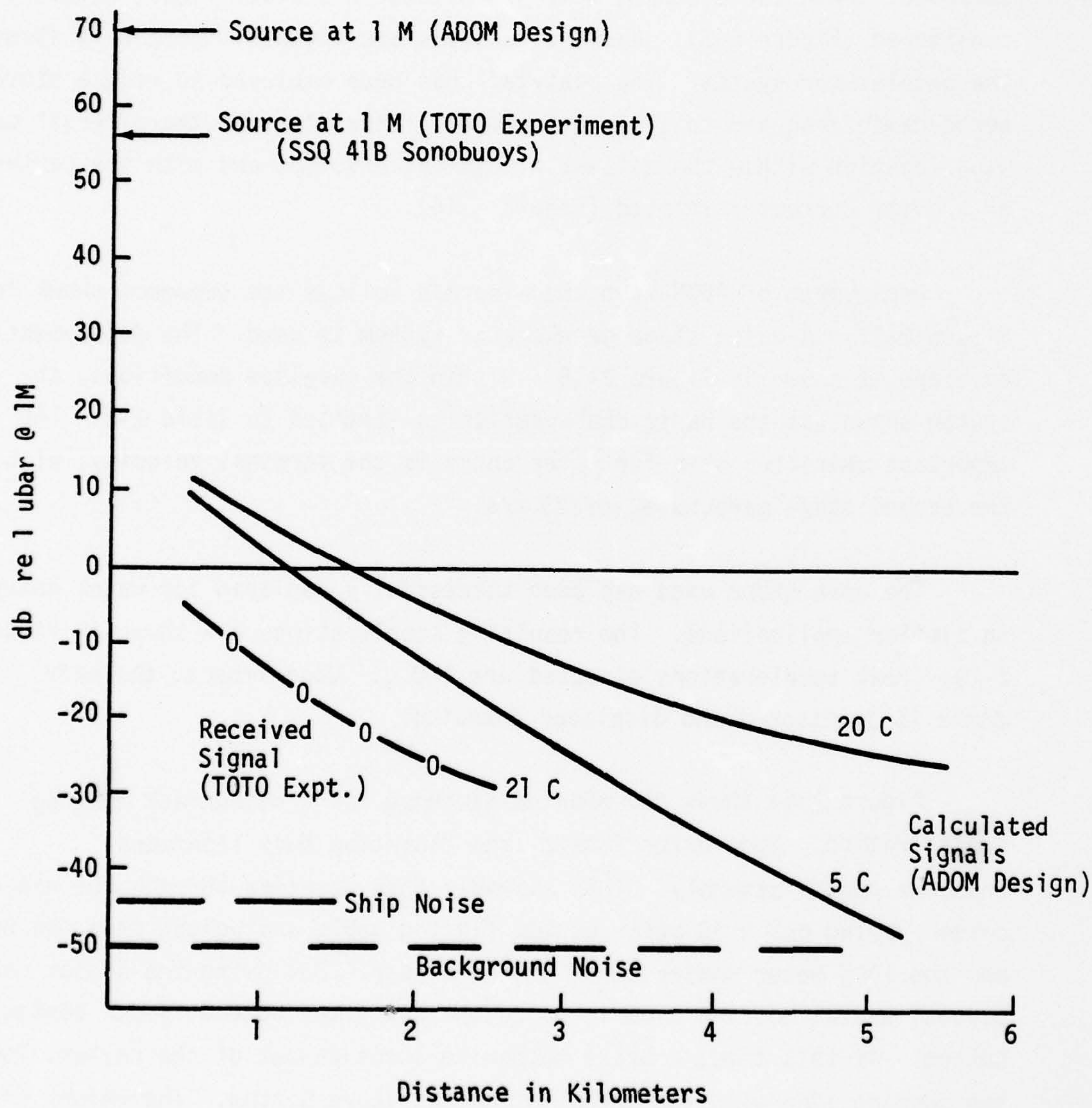

Figure 2-14. Acoustic Data Link Signal Strengths

2.2.4 MECHANICAL SYSTEM AND DEPLOYMENT. The buoy system has been conceptually packaged and consideration made to the store capability with the P3 aircraft, the deployment from the aircraft, and the self mooring sequence. Both the systems, with and without a surface float, have been considered (Figure 2-3). Basic dimensions are shown. Figure 2-15 shows the decelerator system. The boat-tail has been employed to reduce store aerodynamic drag and to allow attachment of the store to the aircraft underwing location within the allowable physical envelope and with the center of gravity correctly located (Figure 2-16).

Deployment of ADOM from the aircraft follows the sequence shown in Figure 2-17. A multi-stage decelerator system is used. The deployment envelope is shown in Figure 2-18. Within the envelope conditions, the system shown has the basic characteristics itemized in Table 2-6. The important characteristic for water entry is the terminal velocity, with the second stage parachute, of 23 m/s.

The nose shape used has been successfully deployed for water entry in similar applications. The resulting accelerations are shown in Figure 2-19. Peak accelerations expected are 100 g. Upon impact, the main chute is jettisoned and displaced downwind.

Figure 2-20 shows the mooring sequence for a subsurface mooring configuration. Upon water impact, the flotation buoy separates from the anchor assembly. This assembly then descends through the water column paying out a 50 meter bottom finding cable and weight from the nose, and the 1500 meter sensor cable from the rear. Following the sensor cable payout, Kevlar mooring line is payed out until the bottom finder contacts bottom. At this time, a brake mechanism stops payout of the Kevlar, locking the mooring line with the anchor 50 meters above bottom. The weight of the anchor then causes the float to submerge 50 meters until the anchor is on the bottom.

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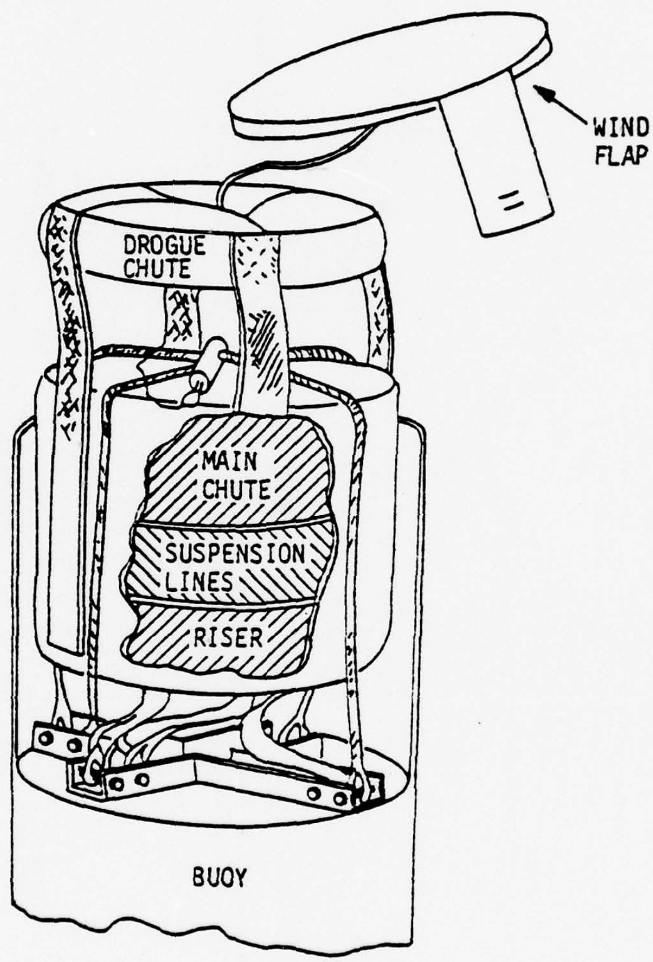

Figure 2-15. ADOM Decelerator System

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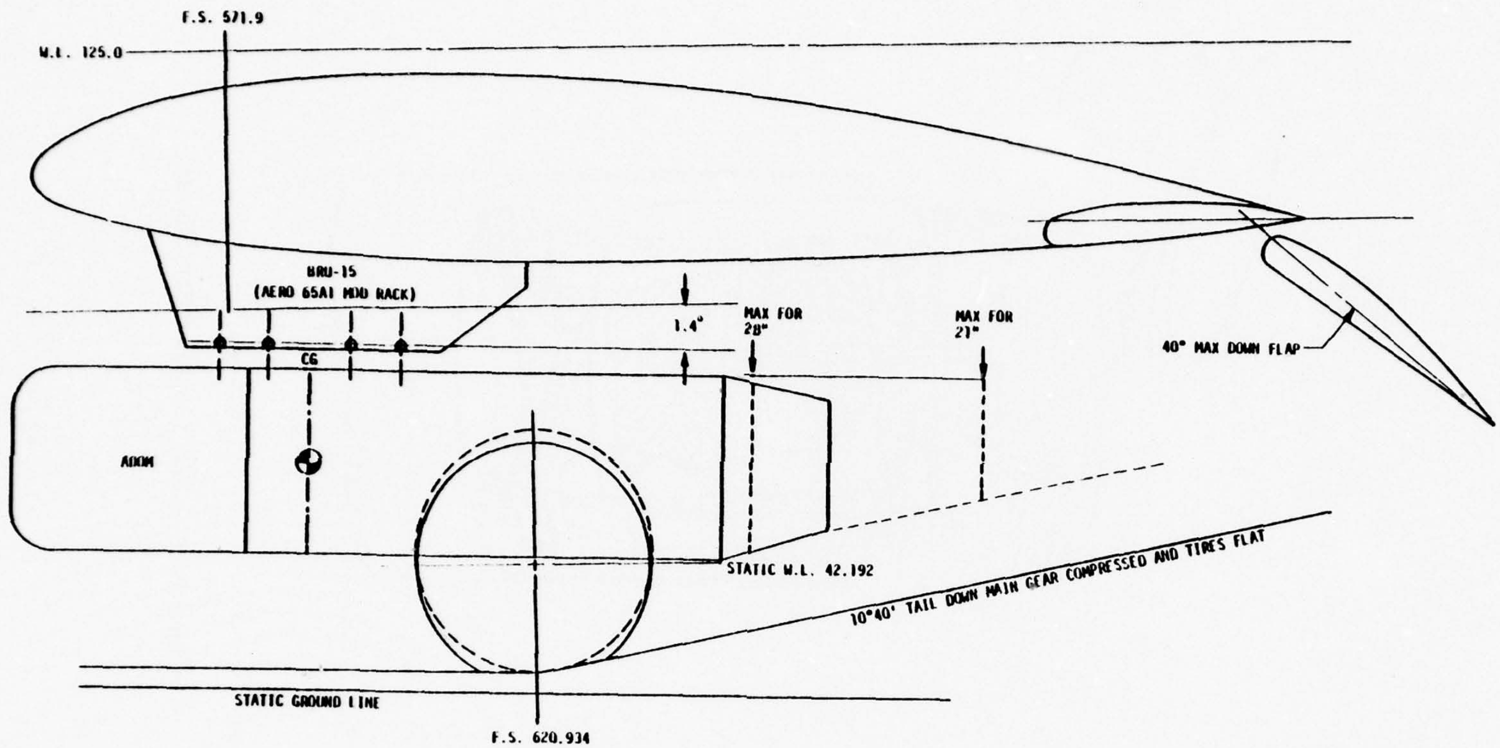

Figure 2-16. P3 Aircraft with ADOM Configuration

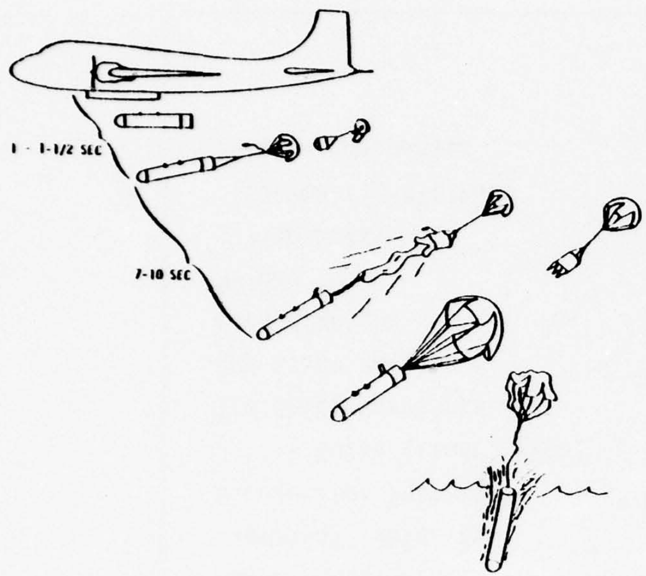

Figure 2-17. ADOM Multi-Stage Decelerator System

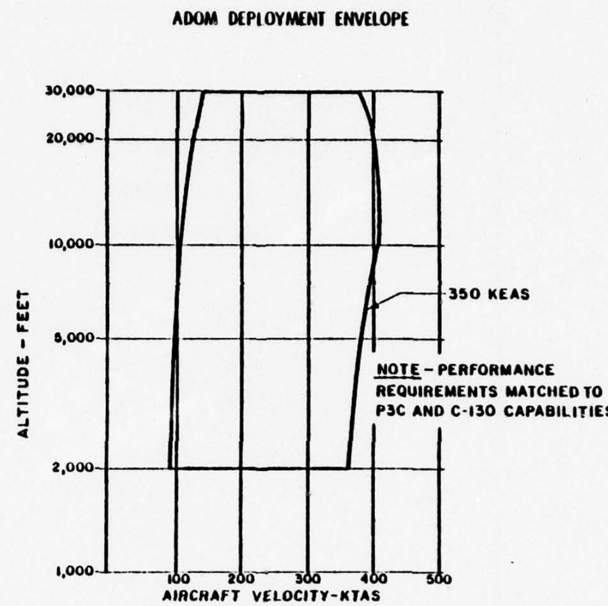

Figure 2-18. ADOM Deployment Envelope

TABLE 2-6. BASIC DECELERATOR SYSTEM CHARACTERISTICS

Buoy Diameter	71 cm (28 in)
"Nose" Configuration	1/4 D. Ogive
"Terminal" Velocity	23 M/Sec
Decelerator Initiation	Windflap
-- Delay (Timer, Pyro)	1.0 Sec ± 20%
1st Stage Parachute	3M Dia Ringslot
2nd Stage Parachute	7M Dia Ringslot
Packed Height	30.5 cm (12 in)
Weight	
Time Delay	7-10 Seconds
Barometric Altitude	1000M ± 333
Jettison Mechanism	Sea Water Switches to Pyro-Electric Release

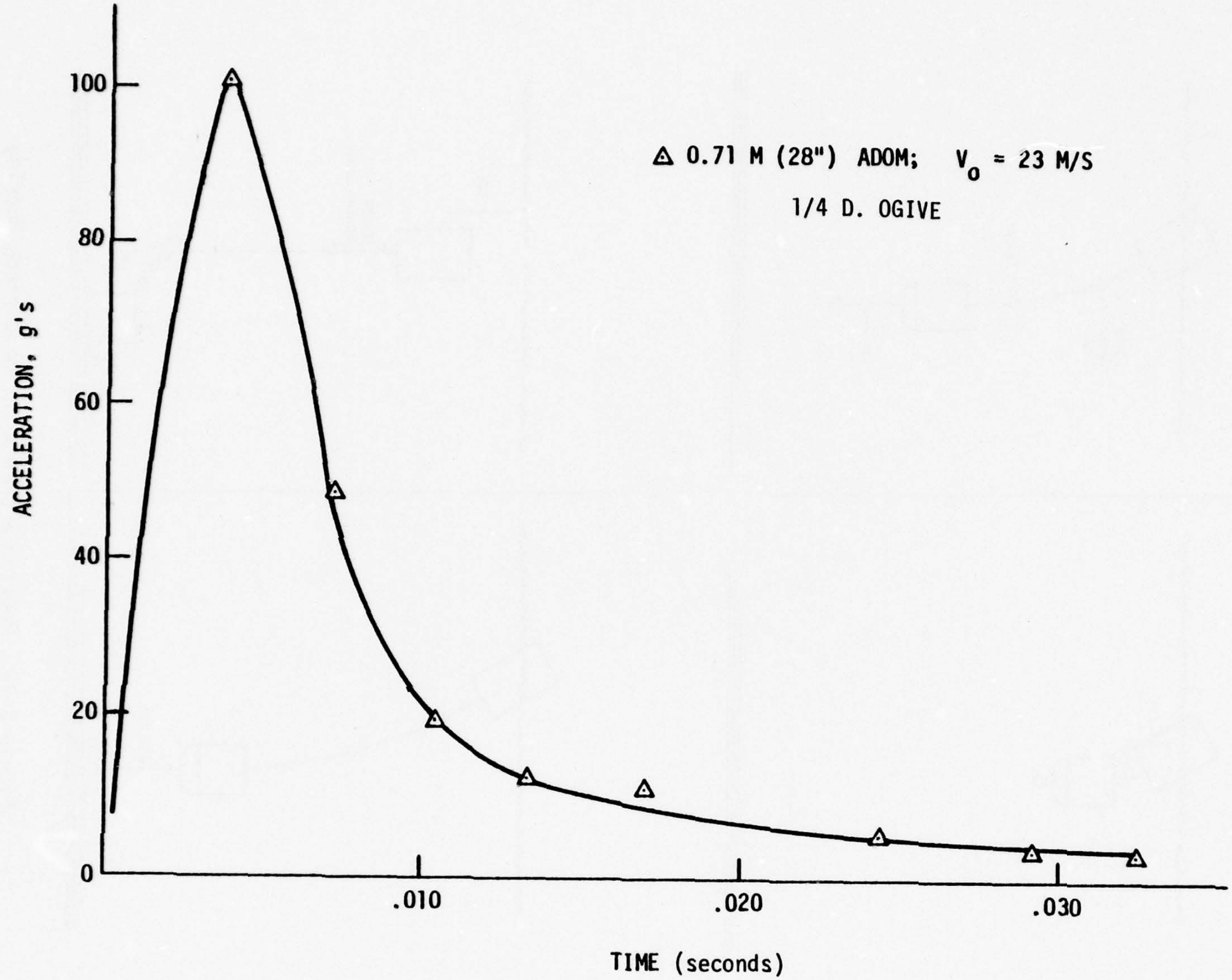

Figure 2-19. ADOM Buoy Water Entry

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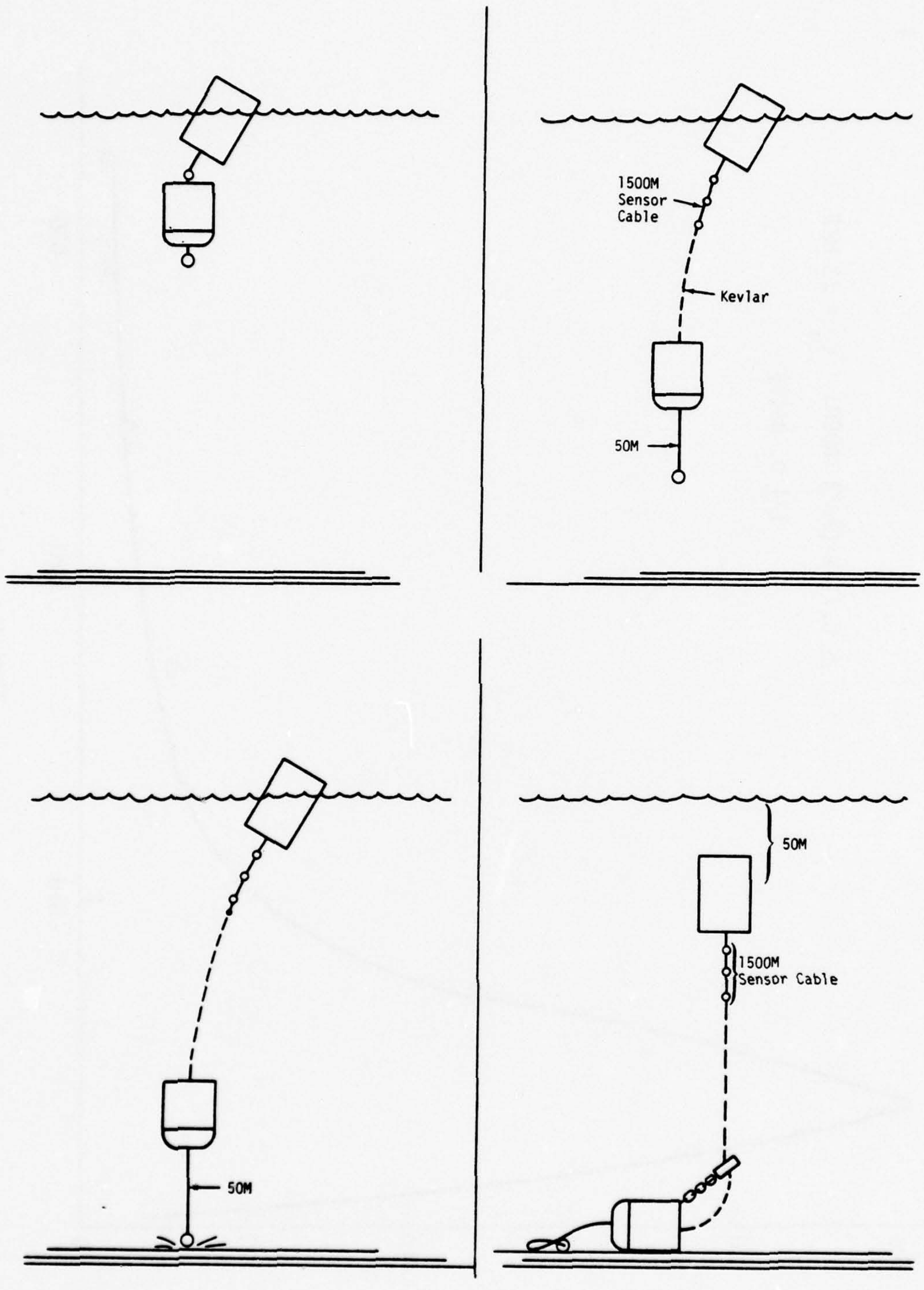


Figure 2-20. Mooring Sequence for Subsurface Mooring Configuration

Figure 2-21 shows a similar sequence for an array which has a surface telemetry float in addition to the subsurface float. The surface float is released at 10 meters below the surface and comes to the surface attached to the subsurface float with an elastic tether line and electromechanical cable.

2.2.4.1 ANCHOR SUB-ASSEMBLY. The ADOM anchor sub-assembly is shown in greater detail in Figure 2-22. It consists of a steel housing which acts as an anchor after complete deployment. It contains a bottom finder which is a lead ball mounted in the nose and is released upon impact by a frangible cover. Fifty meters of cable are attached to this ball which activitates the mooring line brake mechanism. The descent rate of this ball is nearly twice that of the anchor assembly, assuring its complete deployment during payout within the first 1000 meters depth. After separation of the anchor assembly from the buoy, the 1500 meter sensor string deploys. At approximately 1000 meters, the bottom finder weight has been completely deployed. This releases the brake mechanism on the Kevlar mooring line allowing it to pay out under light tension following the sensor string. The anchor assembly continues its descent until the bottom finder contacts the sea floor, causing the brake to be applied to the Kevlar mooring line. This braking force is sufficient to allow the brake mechanism to separate from its mounts by corrodible shear pins, carrying it outside the anchor housing but attached to the side of the housing by chain to eliminate chaffing and to optimize the angle of force on the anchor causing it to dig in. After braking, the anchor weight then pulls the surface buoy under to 50 meters.

2.2.4.2 Mooring Line. The mooring line consists of 6000 meters of Kevlar line 0.18 in (4.3 mm) OD, wound in a special package. The line feeds out from the center and is packed with one backturn per 2π radians to eliminate turns in the line during deployment. The package is encapsulated with a special compound to provide a smooth payout.

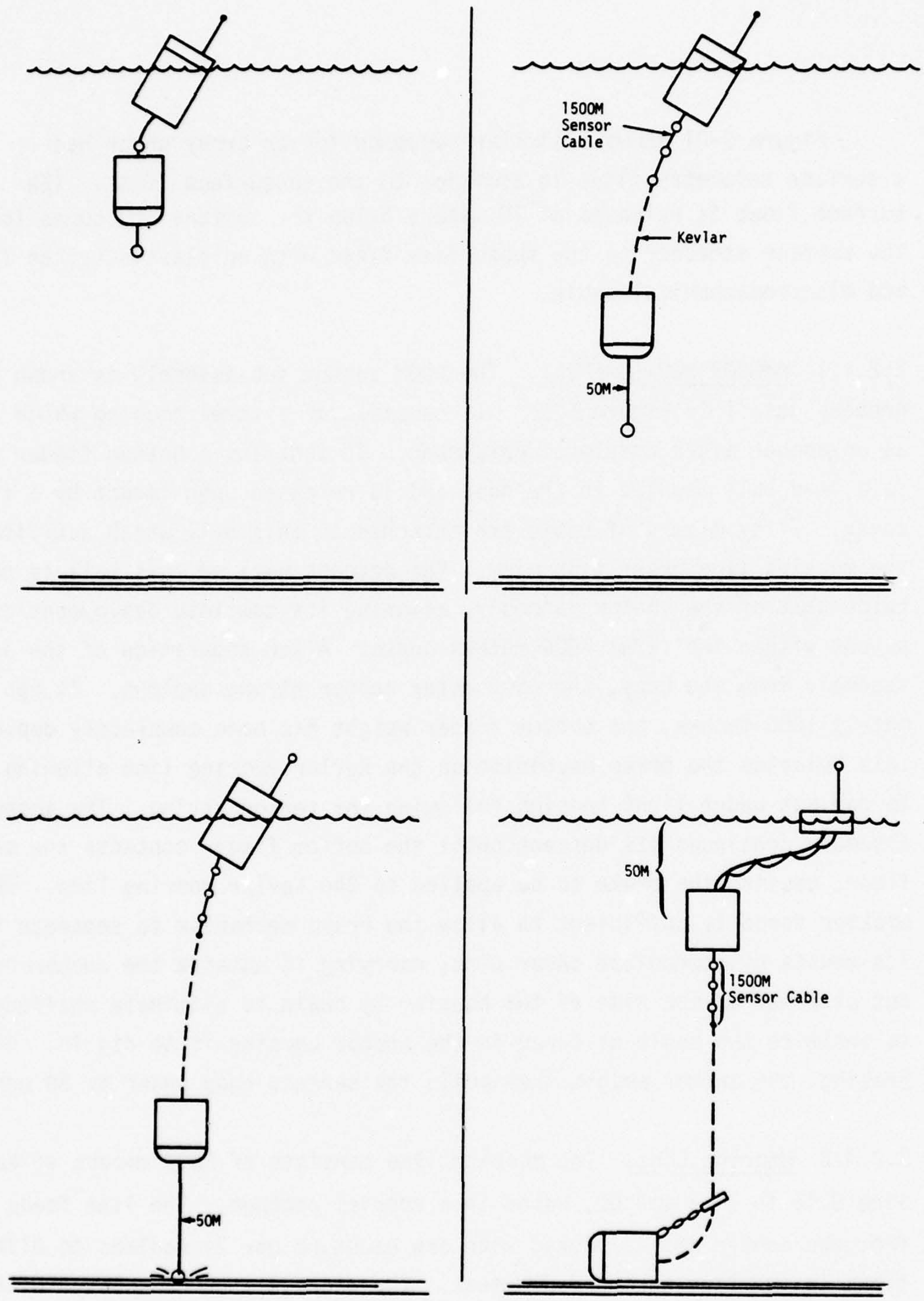
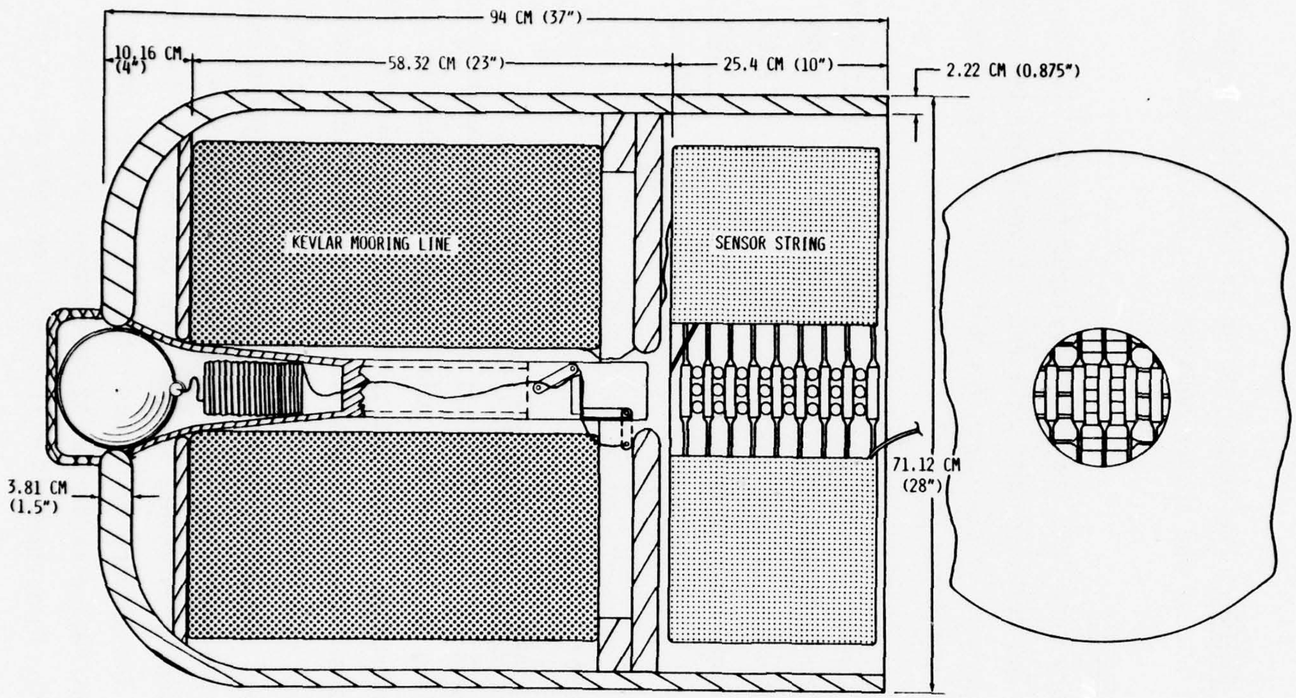


Figure 2-21. Mooring Sequence for Array with a Surface and Subsurface Float



ANCHOR SHELL	425.4 KG,	938 LBS.
KEVLAR LINE	93.4	206.
SENSOR LINE	116.1	256
	634.9	1,400.

Figure 2-22. ADOM Mooring Assembly

2.2.4.3 SENSOR STRING. The sensor string is 1500 meters long. It is packaged to pull out of the anchor housing in a controlled manner.

2.2.5 COST ESTIMATE.

Preliminary cost data has been developed for the ADOM open ocean configuration. The detailed cost data and rationale are presented in Appendix B. A summary of the costs for the ADOM surface/subsurface buoy configuration is presented below:

Electronics and Sensor System	$ 12,200*
Surface/Subsurface Configuration	7,500
Mooring System	7,600
Decelerator Assembly	1,800
	$ 29,100

*Assume a 20 sensor string.

2.3 ICE COVERED OCEAN SUSPENDED SYSTEM.

A substantial amount of data has been developed relating to the problem of landing an ADOM on the polar ice, penetrating the ice, deploying an instrument string and surviving to communicate. The ADOM progress report in August 1977 provided some of this information. There was an additional need to develop further concepts for ice penetration; study the various concept alternatives; and select a system concept which obtains optimum reliability, cost, and effectiveness consistent with the technical constraints and limiting technologies for Arctic applications. The University of New Hampshire has been engaged to conduct through-the-ice research and development on the Arctic engineering aspects of ADOM. This research will be divided into phases as follows:

Phase I - Concept Definition Phase
Phase II - Concept Validation Phase

2.3.1 PHASE I - CONCEPT DEFINITION PHASE.

A concept definition phase, which consists of testing previous assumptions, establishing the bounds and the performance constraints of the several potential systems for drilling a hole in eight meters of ice, and then deploying an instrument string, will be conducted. This will continue to a point where each system concept may be objectively measured against competing concepts. The preferred system will be evolved to a design concept with a fully defined view of strengths, weaknesses, costs and probabilities of success. Concept definition consists of the following elements:

a. assessment of Arctic technologies and data bases,
b. examination of ice penetration system concepts,
c. analysis of system characteristics and tradeoff studies of ice penetration concepts,
d. development of a preferred design concept for ice penetration, and
e. recommendation for a concept validation phase.

2.3.1.1 Assessment of Arctic Technologies and Data Bases. Many workers have considered the problems of ice drilling in polar regions; principal among these are the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), the Canadian Polar Shelf Study, and the extensive studies of the Russians and Japanese. The full extent of this technology will be gathered, assimilated and abstracted. Assumptions made earlier in the ADOM program will be verified.

2.3.1.2 Examination of Ice Penetration System Concepts. A detailed examination will be made of the four drilling systems that show some potential for unmanned applications. These are:

a. Electrothermal - a battery driven resistive element heats the ice and lowers the instruments while leaving the main system package on the ice surface.

b. Chemothermal drilling - the energy source is a chemical, releasing heat on command or on contact with the ice.

c. Impact penetrometers - creates a hole through the impact of an air dropped element, with the remainder of the system landing by a tethered parachute to reduce deceleration forces.

d. Mechanical augers - unmanned adaptations of existing technology.

The potential for systems that avoid drilling by employing open water deployment in leads will also be examined. A reevaluation will be made of the available ice thickness histogram and of the ice characteristics.

2.3.1.3 Analysis of System Characteristics and Tradeoff Studies of Ice Penetration Concepts. A detailed analysis will be made to establish specific characteristics of each system concept. These system parameters then will be compared to determine an optimum system concept.

System characteristics which will be included in the studies and tradeoff analysis are:

- energy requirements
- size
- weight
- applicability of available technology
- portability/ease of air deployment
- failure modes
- reliability and survivability
- Arctic environment compatibility
- cost
- prototype fabrication time
- compatibility with existing ADOM components

2.3.1.4 Development of Design Concept for Ice Penetration. After the specific optimum parameters are determined, a design concept will be developed. An initial system design will be made in sufficient detail to support a concept validation model.

2.3.1.5 Recommendation for a Concept Validation Phase. A design concept of a prototype system will be selected for fabrication that will have the maximum probability of success. One design concept for ice penetration will be recommended. Recommendations for undertaking a validation study will be made by 1 July 1978.

2.3.2 PHASE II - CONCEPT VALIDATION PHASE.

The design proposed under Phase I will be constructed, laboratory tested, evaluated at the University's Lake Winnipesaukee facility, and prepared for an Arctic test under appropriate field conditions.

The purpose of Phase II is to conduct detailed technical studies of the recommended penetration concept, to design and develop a working prototype of the penetration system (devoid of air deployment hardware, electronics and sensors but compatible with the other components of ADOM), and to conduct preliminary tests with the prototype.

A series of tests will be run during February 1979 at the UNH Field Station at Lake Winnipesaukee. These tests will be used to obtain engineering data on the ice boring system. These data will be used to validate the prototype model and to solve operational problems which would affect Arctic testing of the system. Arctic field tests are expected to take place in the April to May period of 1979.

SECTION III

FUTURE ACTIONS

3.1 GENERAL.

This section describes the actions, further analysis and investigations necessary in the continuation of the ADOM Feasibility Study. The open ocean system and ice covered ocean suspended configurations are discussed below.

3.2 OPEN OCEAN SYSTEM.

The planned actions during 1978 are as follows:

a. Continue the hydrodynamic analysis to determine the need and feasibility of using antistrumming fairing and the antenna carrying capability of the surface buoy.

b. Develop the design of the subsurface buoy, surface buoy, tether, associated release mechanism and integrate with the anchor assembly so that the complete system can be specified.

c. Develop the processor and sensor array, and evaluate in a drifting buoy field test.

d. Develop and test other critical components such as cable payout mechanism, bottom finder, tether, and battery assemblies.

e. Refine cost estimates and perform cost tradeoff analysis.

3.3 ICE COVERED OCEAN SUSPENDED SYSTEM.

The planned actions during 1978 are as follows:

a. A preferred system will be identified and evolved to a design concept with a fully defined view of strength, weaknesses, costs and probabilities of success.

b. Upon completion of (a) above, the recommended penetration concept will be developed and prototyped for testing.

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APPENDIX A

ANALYSIS OF A TWO STAGE ADOM MOORING

APPENDIX A

ANALYSIS OF A TWO STAGE ADOM MOORING

A.1 GENERAL.

A computer model of a two stage ADOM mooring, with a tether line to link the surface float with the main subsurface buoy, was developed. An analysis was performed. The results are presented below. The computer model of the two-stage ADOM mooring showed that the tether parameters must be carefully selected.

A.2 MOORING REQUIREMENTS.

The surface float must be restrained against the ocean current, strongest at the water surface, yet must be free to ride over the wave crests. Furthermore, the electromagnetic cable must be protected from fatigue failure as the tension oscillates with each passing wave, and from impulse failure as waves "slap" the surface float. The drag added by the tether and surface float must not cause the subsurface float to dip below its crush depth. And finally, the tether line must not be so long that it would foul itself or the deep line in a static ocean.

A.3 OPTIMIZING CONDITIONS.

Figure A-1 is a sketch of the mechanical components used to meet the optimized conditions. The E/M cable is the same as in the deep mooring line, and is used to tether the surface float and carry the data from the main buoy to the surface.

A heavy rubber bungee is added near the surface float, and the E/M cable lashed to it in bights such that the E/M is loaded only after the bungee reaches a maximum strain. The length of the bungee and tether are selected so that their combined length, when hanging under their own weight, just reaches the main buoy in a static ocean (Figure A-1 part (a)).

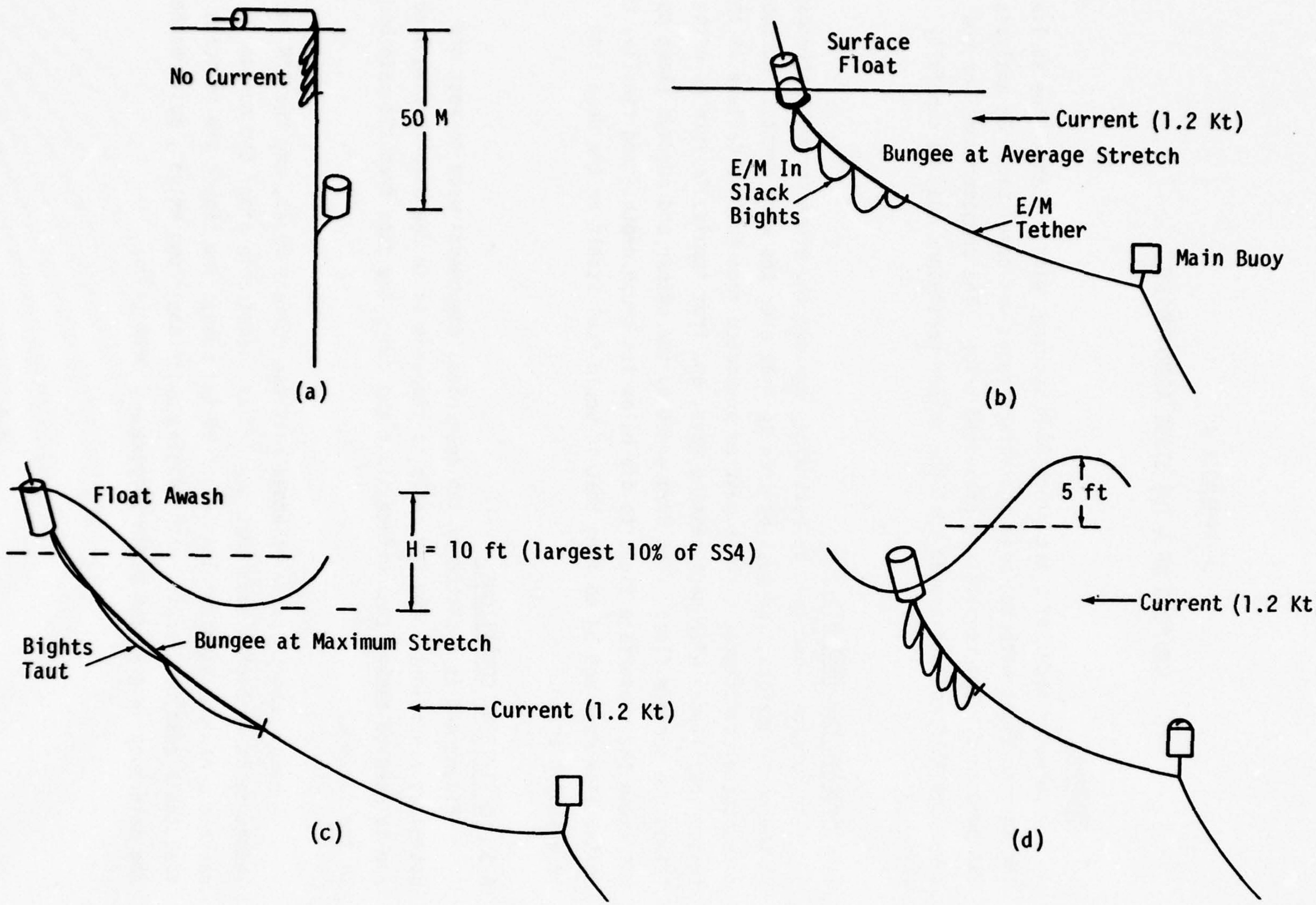


Figure A-1. Mechanical Components Used to Meet the Optimized Conditions

Under the operational ocean current, with no waves, the bungee is partially stretched, to some average tension, part (b). In part (c), the crest of the "maximum operational wave" is passing and the bungee is stretched until the E/M bights have just come taut and the surface float is just awash. Part (d) shows the float a moment later when the trough of the wave passes and the bungee is strained less than average, but more than in a static ocean. The surface tether was "optimized" to satisfy conditions (a) through (d) using the ratio of the difference between the maximum tension in part (c) and the minimum tension in part (d) to the average tension in part (b) as a measure of the stiffness of the tether. The environmental conditions are specified in Table 2-1 and Figure 2-2.

A.4. MOORING PARAMETERS AND CONSTRAINTS.

In order to perform this optimization, the non-linear stress-strain relationship for the bungee was required. A mathematical formula was devised by digitizing and fitting curves presented in Reference 12 (Figures 12 and 13) using the formula:

$$\text{strain}=\text{stress}\ (A_1 + \sqrt{\text{stress}}\ (A_2 + \sqrt{\text{stress}}\ (A_3 + \sqrt{\text{stress}}\ \cdot A_4)))$$

Table A-1 gives the coefficients A_1 through A_4, as well as other fixed constants used in the optimization.

In the early stages of the optimization study, an additional factor was considered, namely, the effect of reducing the size of the surface float and "adding it back" as a subsurface "pennant float" located somewhere along the E/M tether line. The result was consistent - make the surface float as small as possible, and merge the "pennant float" with the main subsurface buoy. In all subsequent work, the surface float was taken at 20, 40, 60 and 80 percent size reduction, as well as the original postulated size taken from the packaging study. The final size of the surface float will probably be limited by the weight or volume of its payload package.

TABLE A-1. FITTED COEFFICIENTS FOR STRAIN VS STRESS FUNCTIONS

COEFFICIENT	VALUE	X	EXPONENT OF 10
A1	2.734759		-3
A2	5.338754		-4
A3	-2.423850		-5
A4	2.726240		-7

A.5. TETHER LENGTH.

Figure A-2 shows the length of the two segments of the tether line required to satisfy conditions (a) through (d) on Figure A-1. The lengths vary so slightly with reductions in surface float size that the other curves are not shown. The "angularity" of the curves in this and subsequent figures is a product of the plotter software; smooth curves through the "corners" should be used for interpolating from the graphs. The total length of E/M cable required for the tether is the length of the bare segment plus 4 times the length of the bungee segment, in order to have the E/M bights come taut at a bungee strain of 3. The sum of the lengths of bare E/M and bungee is always nearly 50 meters in order to satisfy condition (d).

A.6. BUNGEE DIAMETER.

Figure A-3 shows the nominal (relaxed) bungee diameter that satisfies the optimization requirements as a function of the allowed tension variation due to wave action and the size of the surface float. The diameter depends much more strongly on the size of the surface buoy (which determines the average tension) than on the variation allowed in the tension.

A.7. SUBSURFACE BUOY DIP.

Figure A-4 shows the increase in depth of the main subsurface buoy in the operational ocean current, compared to its depth in no current (50 m). As in Figure A-3, the allowed tension variation is the independent variable and separate curves are given for different sized surface floats.

Reducing the size of the surface float produces a modest benefit, but the curves show a steep penalty to hold the tension variation (peak to peak) less than about 15 percent of the average tension. This penalty is caused by the drag of the large diameter bungee, which must be made much longer in order to keep the tension nearly constant, and then is stretched to a larger average strain.

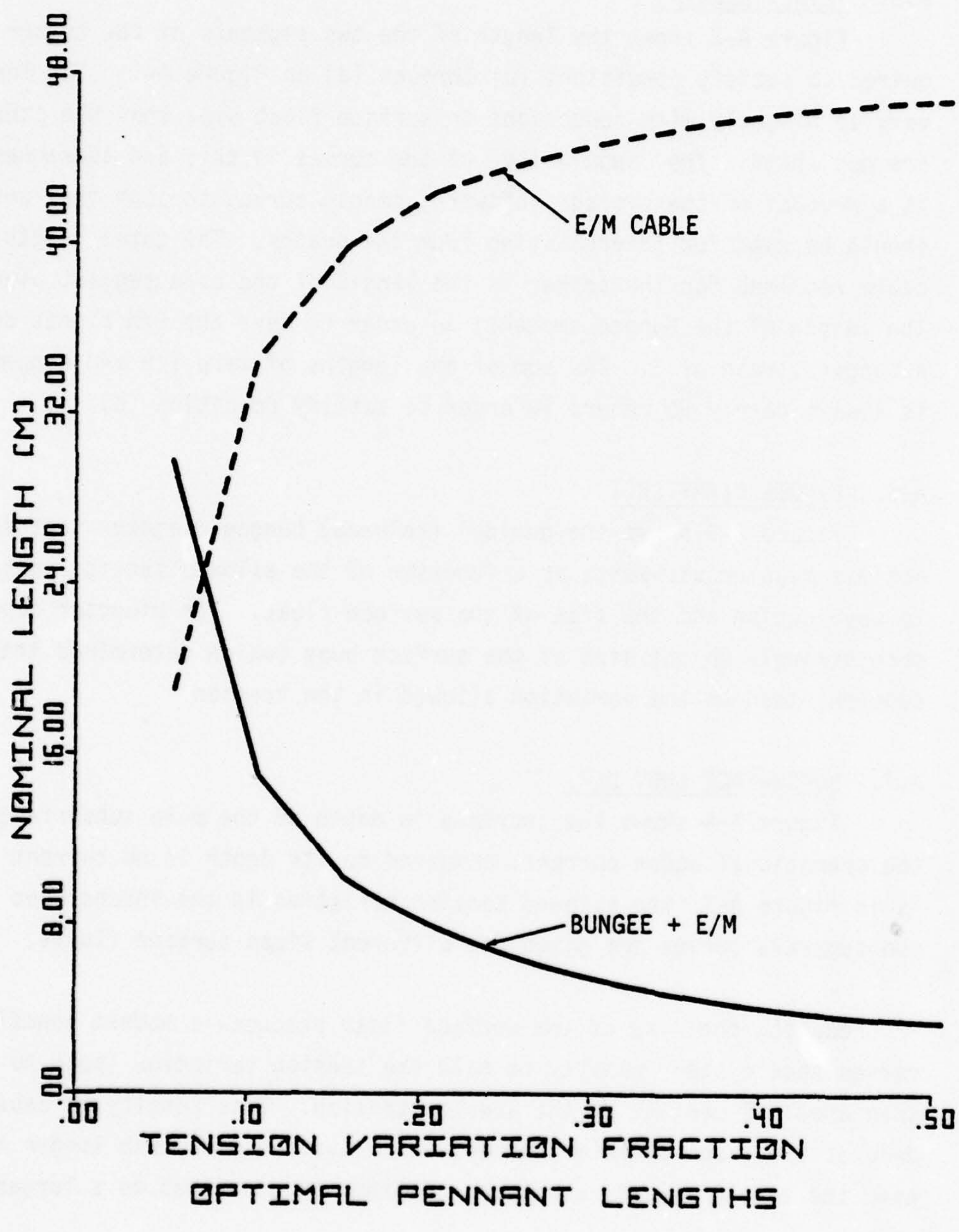


Figure A-2. Tether Line Length

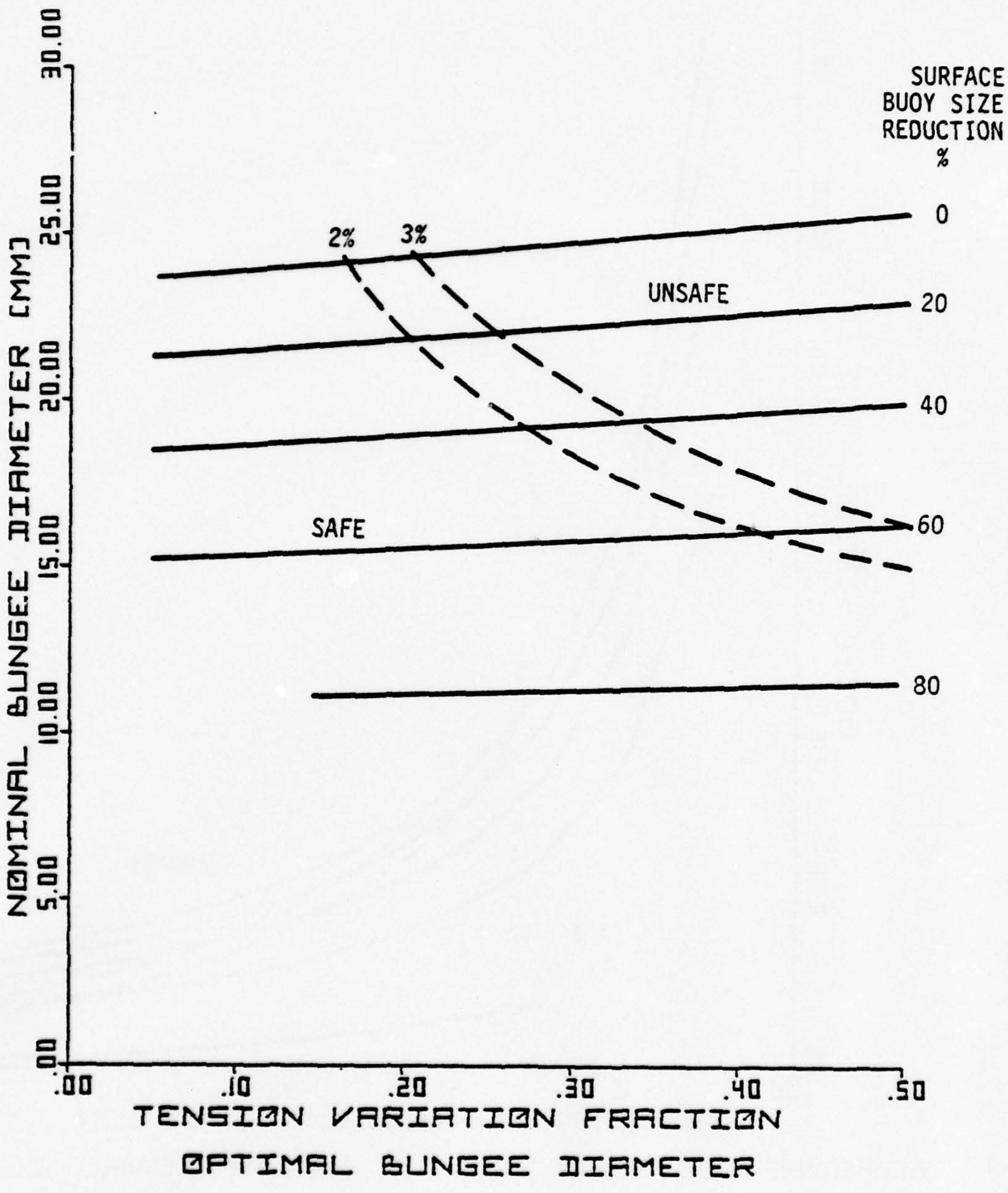


Figure A-3. Bungee Diameter

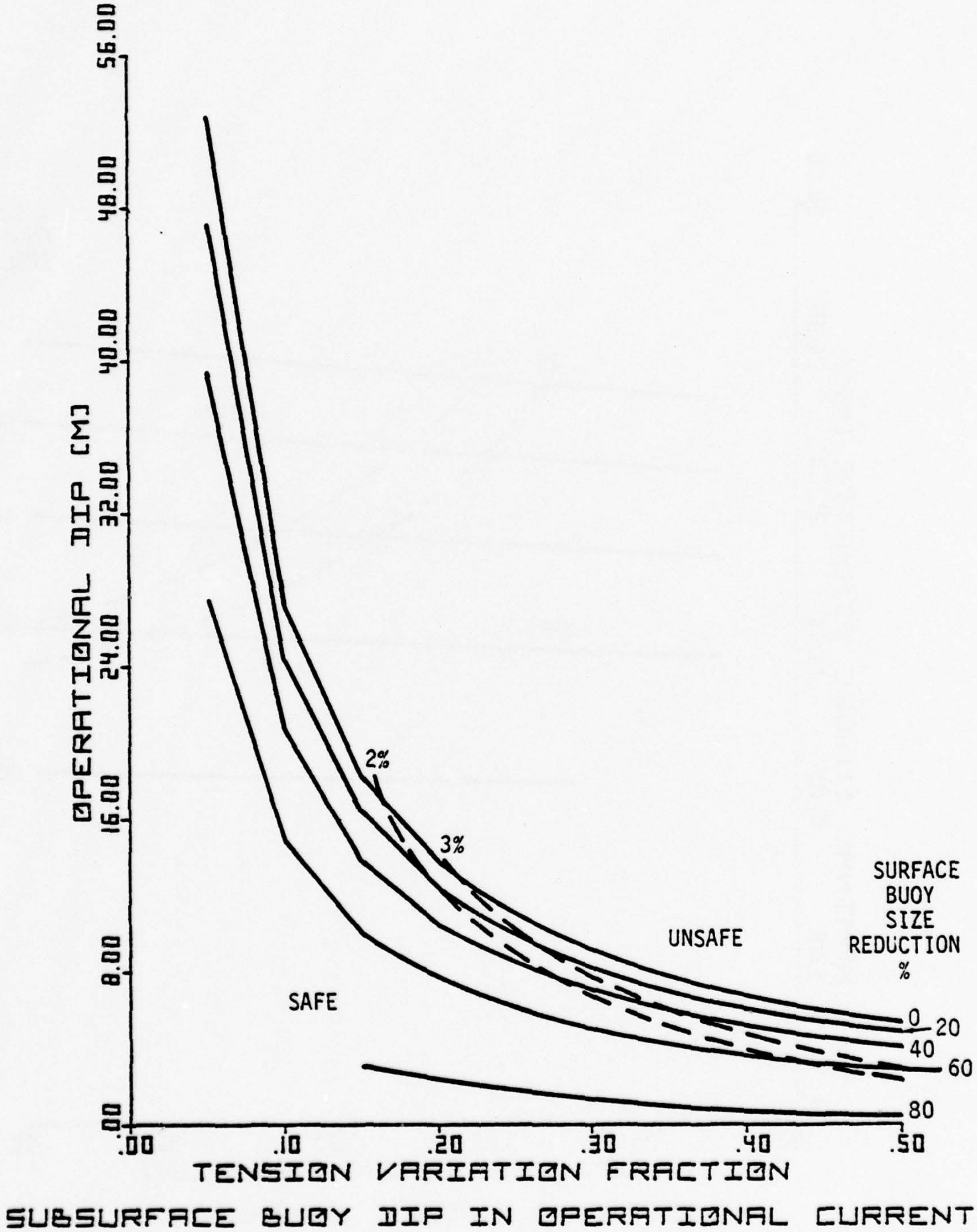


Figure A-4. Subsurface Buoy Depth

When the current speed increases to the survival condition, the subsurface buoy dip is much greater, as shown by Figure A-5. In this case, the size of the surface float is more important than the allowed tension variation. The buoyancy of the larger surface floats hold them higher in the profile, where the current speed is greater. The result is more drag transmitted to the main buoy.

A.8. SURFACE FLOAT DIP.

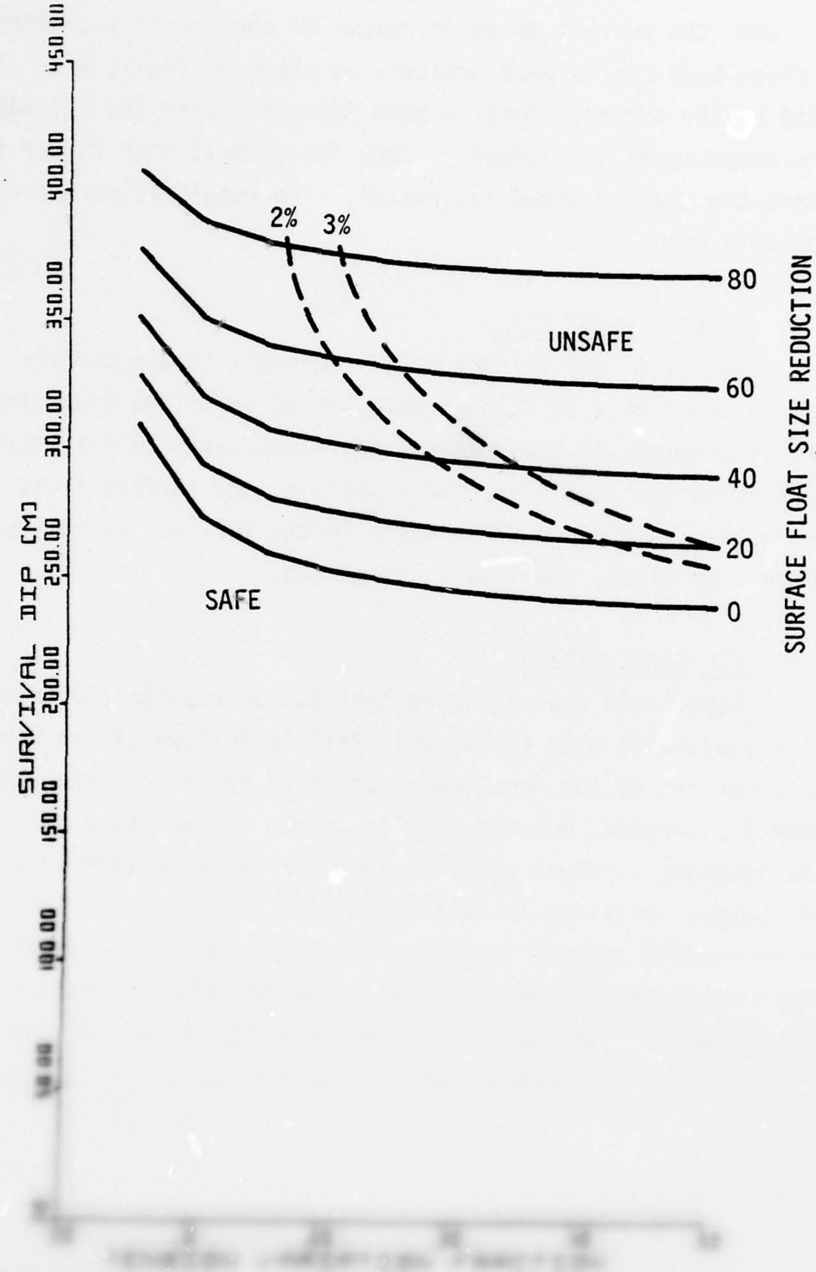
Condition (c) (Figure A-1) requires that the surface float be just awash as the crest of a 10 ft high wave passes by in the operational current. In lesser currents or lower waves, the float has positive freeboard. When the current exceeds the operational profile, the surface float submerges. Figure A-6 gives the surface float depth in the survival current profile. The larger the float, the less it submerges.

A.9. E/M CABLE FATIGUE.

Woods Hole Oceanographic Institution reports (Reference 6) that mooring wire subject to wave forces will fail in fatigue if the wave forces exceed 2 to 3 percent of the breaking strength of the wire. When the variation is less than 2-3 percent, mooring life in excess of two years has been obtained. Taking the breaking strength of 0.169-inch E/M cable as 2370 lbs, the acceptable limit of dynamic variation in tension is 47.7 to 71.1 lbs. Table A-2 gives the corresponding tension variation fractions as a function of surface float size. The intersection of these tabulated values with the curves plotted on Figures A-2 through A-6 divide the figures into "safe" and "unsafe domains". "Unsafe" indicates the probability of mooring failure through fatigue of the mooring line.

A.10. BUNGEE RESONANCE.

The foregoing optimization procedure assumed, for simplicity, that the lower end of the bungee is held motionless, and that the surface float simply follows the orbital motion of the surrounding water. That is, the wave extends the bungee and relaxes it. The dynamic effects of inertia are not considered.


SURVIVAL DIP (M)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
2%
3%
UNSAFE
SAFE
80
60
40
20
0
SURFACE FLOAT SIZE REDUCTION %

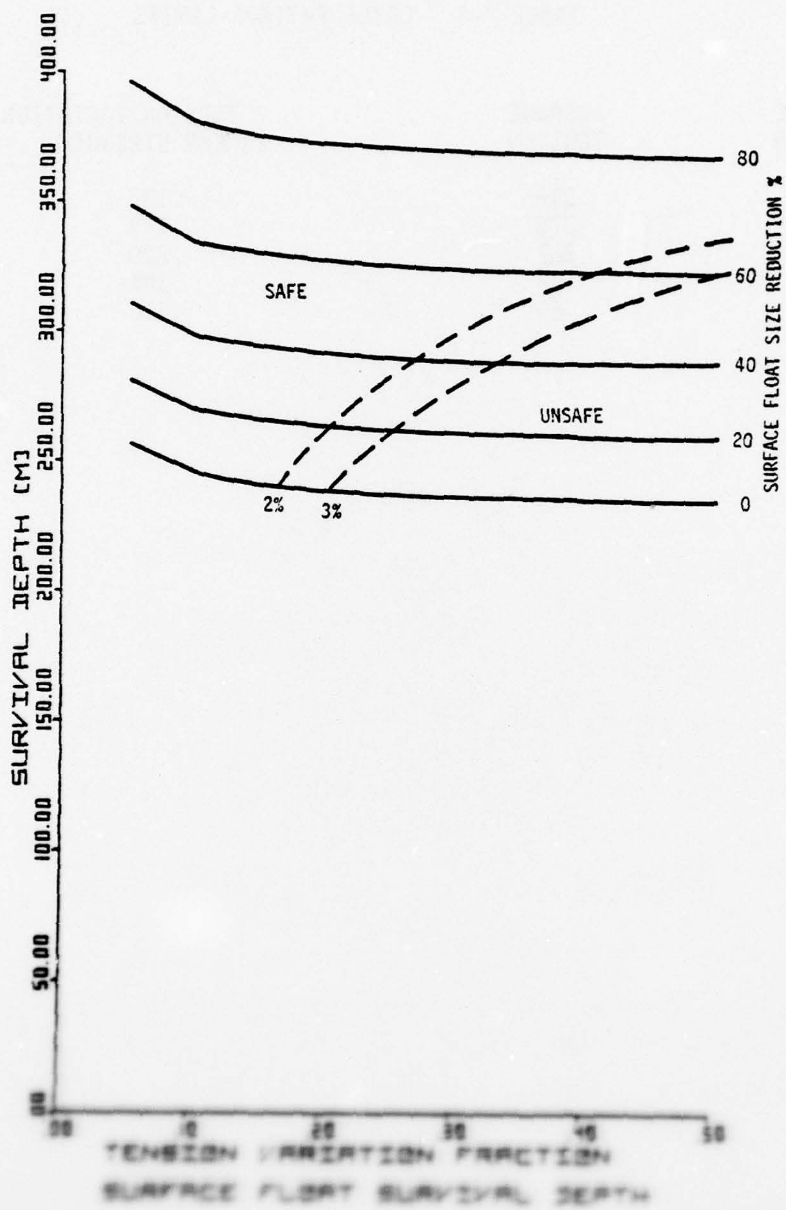


Figure [illegible]. Surface Float Depth

TABLE A-2. CABLE FATIGUE LIMITS

BUOY SIZE REDUCTION	AVERAGE TENSION	TENSION VARIATION FRACTION 2% E/M STRENGTH	3% E/M STRENGTH
0	345	.137	.206
20	276	.172	.258
40	207	.229	.344
60	138	.344	.515
80	69	.686	1.03

Figure A-7 shows the resonant period of the surface float as a function of the tension variability fraction. It is based on the simplest model of a mass on a massless spring, using a linear spring rate for rubber evaluated at the in-situ strain.

Taking 8 seconds arbitrarily as the minimum acceptable resonant period and reading Figure A-7 gives 0.2 as the maximum acceptable tension variation. By comparing with Figures A-2 through A-6, it is evident that the 8 second limit is compatible with the 3 percent fatigue limit for the full-sized surface float, and remains compatible with all smaller sizes.

A.11. SNAP LOADING.

The "snap loading" that occurs when a slack cable comes taut against an inertial load can cause failure in a system that is statically safe. This kind of loading is conceivable for the strain-limiting E/M cable hanging in bights from the bungee. However, since the drag of the surface float varies as the square of the current speed, the "window" for snap loading can be expected to be narrow. If the surface current is less than the operational specification, the strain in the bungee will be less, so that a larger wave is required to tighten the E/M cable. At zero speed, for example, using a design tension variability of 0.2, the bungee length is about 8 meters and the zero current strain is virtually zero. In order to bring the strain limiter into play, 1/2 the wave height must equal 3 times the bungee length, so that a mountainous 48 meter wave is required.

At the other extreme, increases in the operational current profile speeds will quickly drag the surface float under, where the motion amplitude decays with depth, and the wave slap forces do not occur.

In the "window" of the current speeds and wave heights near the design specification, it is possible to produce snap loads. Yet even here, there are a number of factors that will tend to smooth the loading.

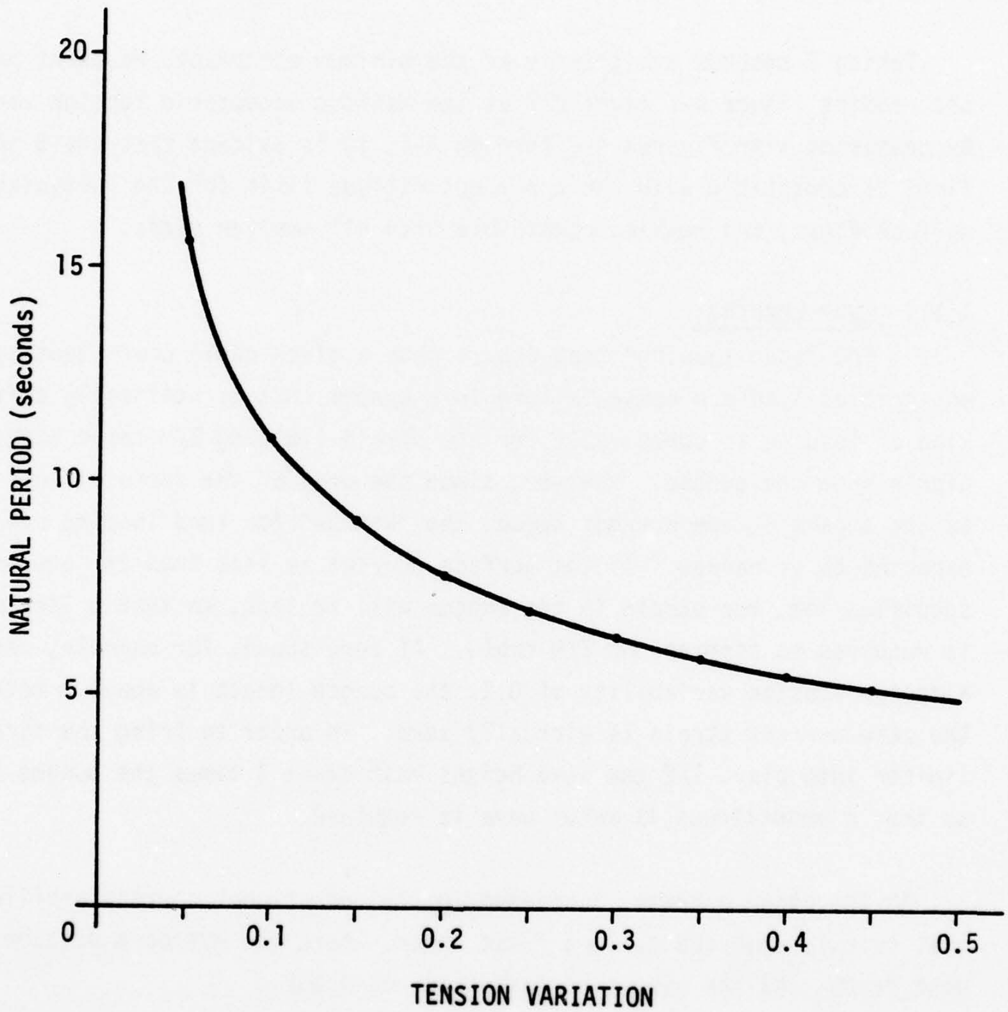


Figure A-7. Resonant Period of the Surface Float as a Function of the Tension Variability Fraction

a. As the bights come taut, the ratio of the transverse displacement of the center of the bight to the tangential displacement of the ends becomes large. This would be of little consequence in air, but will produce a damping force in water.

b. The bungee is not a straight line as modeled, but hangs in an arc. The deep end is not fixed, but attached to the E/M pennant. The snap load is partly absorbed by straightening the arc of the pennant.

c. The surface float will not follow the sea surface precisely. Part of the load will be dissipated by moving the float across the water trajectory.

A.12. SURFACE MOORING CONCLUSIONS.

The curves shown in this section represent the set of possible ADOM surface mooring parameters. It remains to select one design as the "best" design tradeoff. Two of the figures stand out because they show areas of distinct design advantage and disadvantage. Figure A-4 shows a pronounced penalty for designs with a tension variation fraction less than about 0.15; the subsurface buoy dips well below its design depth. Figure A-7, on the other hand, shows the penalty for allowing a tension variation fraction greater than about 0.15; the resonant period of the bungee falls well into the range of common ocean wave periods. Using 0.15 as the design criterion, the remaining mooring parameters may be read from the curves. These are shown in Table A-3 for the full-size surface float.

TABLE A-3. RECOMMENDED ADOM SURFACE MOORING PARAMETERS

Float Diameter	71.0 cm (28 in)
Float Length	50.8 cm (20 in)
Bungee Diameter	23.6 mm
Bungee Length	10.0 m
Bungee Resonant Period	9 s
E/M Pennant	39.6 m
Total E/M in tether	79.6 m
Subsurface Buoy Dip,	
Operational	18. m
Survival	260. m
Surface Float Depth,	
Survival	242 m

APPENDIX B

ADOM COST DATA

APPENDIX B

ADOM COST DATA

B.1. GENERAL.

The purpose of this Appendix is to present preliminary costing data for the Air Deployed Oceanographic Mooring (ADOM). The methodology and cost data for the open ocean configuration will be presented. The configuration for the Ice ADOM has not been finalized; therefore, cost data will not be presented.

The estimates were developed by the participants involved in the ADOM Feasibility Study. Sufficient design work has been performed to allow the definition of a typical component makeup and to estimate fabrication costs. Costing was conducted separately for the mooring assembly, sensor and electronic subsystem, decelerator system, surface and subsurface buoys. Prices for individual components were acquired and then summed to produce a cost figure. The detailed costs and rationale for each of these subsystems are presented below.

B.2. MOORING ASSEMBLY.

The costs for the mooring assembly are presented below:

Jacketed Kevlar Lower Cable (quotation)	
6000 m lengths Kevlar Philystrand P529-7x7 .134J baled	$3,960 ea.
Shipping Reel (returnable)	$ 100 ea.
Anchor (quotation)	
Pattern (one time cost)	$ 850 ea.
Anchor (any quantity)	$ 650 ea.
Bottom Finder (Estimate)	$ 600 ea.
Cable Lock-up Mechanism (Estimate)	$1,200 ea.
Housing and Packaging (anchor assembly) including machinery (Estimate)	$1,200 ea.

B.3 ELECTRONIC AND SENSOR SYSTEM.

The electronic and sensor system can be broken down into five basic units. They are:

a. Processor
b. Sensor Array
c. Data Storage
d. Battery Pack
e. Telemetry

The assumptions used for costing are:

a. 25 buoys
b. Up to 50 sensors/buoy
c. Five data samples per hour
d. Acoustic telemetry of data
e. Production during 1979

The latter is important especially in regard to memory cost. A solid state memory is highly desirable. Present day costs would make it extremely expensive compared with a digital cassette. However, if only reasonable estimates (forward pricing) of 4K and potentially 16K CMOS RAMS are used, this solid state memory will very quickly be competitive with the cassette.

Figure B-1 shows the cost of a 1.6×10^6 bit memory assembly as it is expected to decourse with time. The prices are based on discussions with both Harris and Intersil representatives and reflect their views based on CMOS history and the NMOS pricing history (which leads CMOS by about one year).

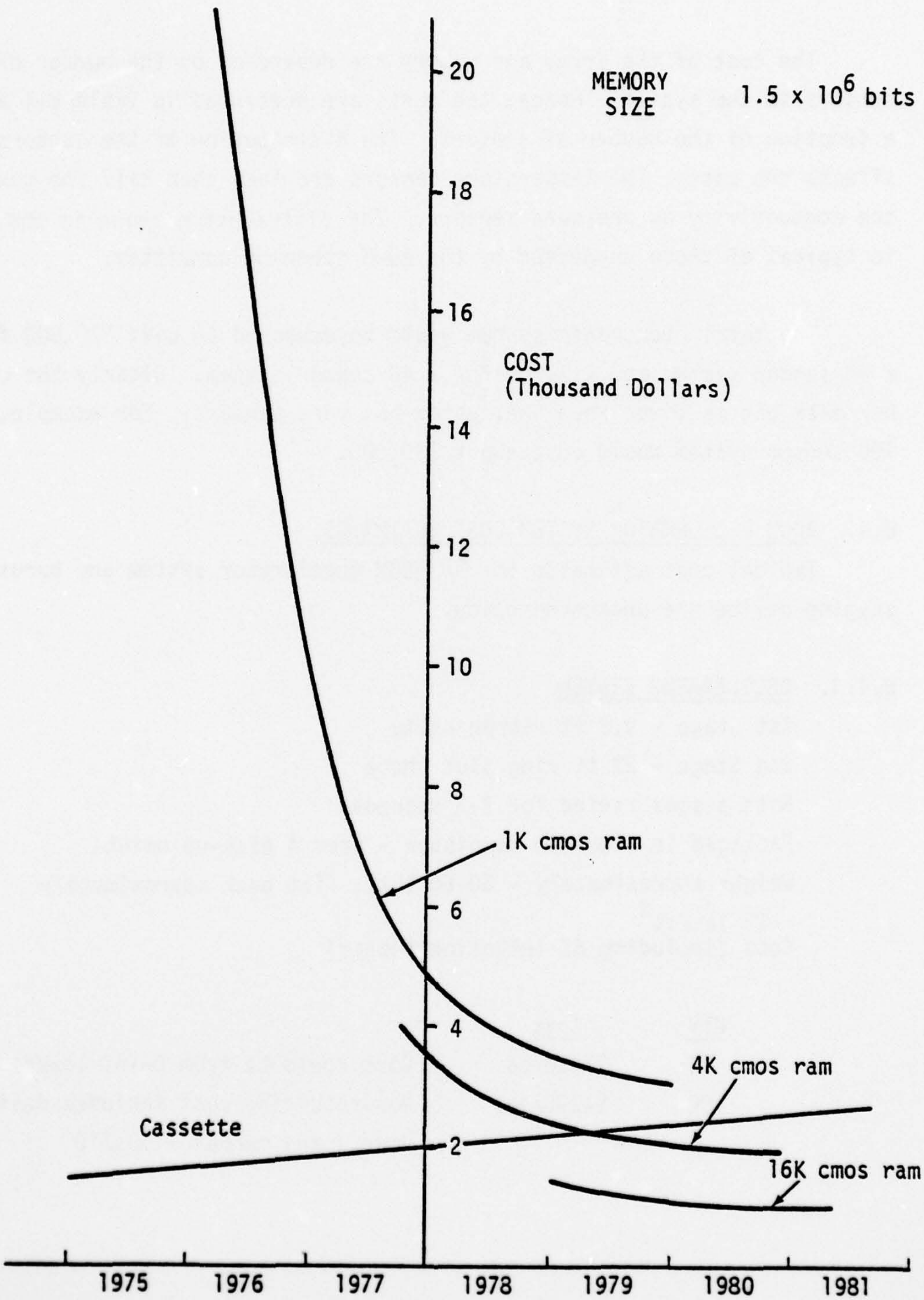


Figure B-1. Projected Solid State Memory Cost (CMOS RAM)

The cost of the array and memory are dependent on the number of sensors in the system. Hence, the costs are presented in Table B-1 as a function of the number of sensors. The distribution of the sensors also affects the cost. The temperature sensors are less than half the cost of the conductivity or pressure sensors. The distribution shown in the table is typical of those suggested by the ADOM steering committee.

The total electronic system would be expected to cost $12,000 for a 20 sensor system and $17,000 for a 40 sensor system. Clearly the cost per data bit is lower when the system has more sensors. For example, a 100 sensor system would cost about $30,000.

B.4. ADOM DECELERATOR SYSTEM COST ESTIMATES.

Typical cost estimates for an ADOM decelerator system and barometric staging device are presented below.

B.4.1. DECELERATOR SYSTEM

1st Stage - 9.5 ft ribbon chute
2nd Stage - 28 ft ring slot chute
Both stages reefed for 2-3 seconds
Packaged in aluminum cannister - uses 4 pick-up points
Weight approximately - 50-60 lbs., firm pack approximately 23 lbs/ft^2
Cost (including 6% inflation factor)

QTY	Cost	
25	$1460/ea.	Cost could be from 0-15% lower
100	$1290/ea.	Non-recurring cost includes design, dwgs., and manual - $3,710

TABLE B-1

COST AS A FUNCTION OF NUMBER OF SENSORS

# Sensors		10	20	30	40	50
Temperature		7	14	22	30	40
Conductivity		0	3	4	5	5
Pressure		3	3	4	5	5
Processor	1.	$2675	2675	2675	2675	2675
Sensor Array	2.	$3985	5665	7290	8910	10200
Ram (5/Hr)	3.	$1300	2335	2975	3500	5200
Battery Pack	4.	$ 600	600	600	700	700
Telemetry	5.	$ 955	955	955	955	955
5/Hr. Ram		$9515	12230	14495	16740	19730

B.4.2. BAROMETRIC STAGING DEVICE.

QTY	COST
25	$335/ea.
100	$138/ea.

B.5. SURFACE AND SUBSURFACE BUOYS.

Cost estimates are as follows:

B.5.1. SUBSURFACE CONFIGURATION.

	Unit Cost (In Thousands)
Buoy, Electronics housing, Aircraft interface (Syntactic Foam 1/2 of the cost quoted)	6.5
Buoy to Decelerator housing (clamp ring)*	.2
Buoy to Mooring Assy (clamp ring)*	.2
	6.9

B.5.2 SURFACE/SUBSURFACE CONFIGURATION.

Surface buoy (no antenna)	1.0
Surface buoy to subsurface buoy	.4
Subsurface buoy	5.5
Clamp rings (3 reg)*	.6
	7.5

* No allowance for separation mechanisms

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B.6 TOTAL ADOM COST.

A summary of the total ADOM fabrication cost is presented below:

Subsurface Buoy Configuration

Electronics and Sensor System	$ 12,200*
Subsurface Configuration	6,900
Mooring System	7,600
Decelerator Assembly	1,800
	$ 28,500

Surface/Subsurface Buoy Configuration

Electronics and Sensor System	$ 12,200*
Surface/Subsurface Configuration	7,500
Mooring System	7,600
Decelerator Assembly	1,800
	$ 29,100

* Assume a 20 sensor string.

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